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Special Issue: Effects of Chemical Protective Clothing on Military Performance

Guest Editors: Gerald P. Krueger and Louis E. Banderet

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(*Continued*)

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Preface to the Special Issue

This special issue of *Military Psychology* reports behavioral sciences research on military performance as it is affected by chemical protective clothing (CPC). These eight articles result from the contributing authors' work in coordinated research programs during the 1980s and early 1990s addressing CPC issues of common concern at U.S. military medical and human engineering research laboratories. Most of the authors participated in symposia on the effects of CPC, convened either by Gerald Krueger at technical meetings of the U.S. Department of Defense Human Factors Engineering Technical Advisory Group from 1985 through 1992 or by Louis Banderet, who coordinated a symposium at the Military Testing Association in 1991.

Even after the demise of the Soviet Union, military forces still concern themselves with maintaining readiness against threats of chemical weaponry. For the last three decades, U.S. military services focused research, development, test, and evaluation programs on the design and field usage of CPC ensembles to protect our forces and to develop improved applications for such equipment to accomplish military missions. The articles here, a cross section of work accomplished in such programs, indicate the findings and the breadth and depth of such applied military psychology research programs.

These articles represent a variety of approaches to studying the effects of wearing CPC on many psychological and performance concerns during accomplishment of military tasks. Challenges include gauging and predicting success or failure of soldiers, sailors, marines, and airmen at performance tasks requiring manual dexterity and psychomotor skills, such as accurately firing a rifle, driving armored vehicles, flying helicopters, operating communication equipment, or plotting coordinates for artillery fire missions on military maps. Other concerns include understanding the physiological implications of operating for extended periods while wearing bulky protective clothing that does not permit metabolic and bodily heat exchange with the environment. For combatants fully garbed in CPC, this means functioning on the battlefield within one's own microenvironment.

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Requests for reprints should be sent to Louis E. Banderet, Military Performance Division, U.S. Army Research Institute of Environmental Medicine, Natick, MA 01760–5007.

The introductory article by Krueger and Banderet summarizes the important implications CPC plays in military readiness to operate on a battlefield contaminated with chemical or biological warfare agents. It places the topic into a psychological performance paradigm characterizing what we know about wearing CPC, sets the stage for operational use of the information we have on the effects of CPC on performance, and points the way toward developmental work that still needs to be accomplished on the design of CPC.

In describing the functionality of CPC used by military forces, Bensel presents data on soldier performance and psychological reactions attributable to mechanical burdens imposed by CPC. She reports degrading effects of CPC such as the gas mask's restriction on the wearer's visual field, the protective hood and gas mask's adverse effect on speech intelligibility and communication, restriction of mobility caused by limited angular movements about joints of the body, and degradation in manual dexterity of finger movements and psychomotor coordination. Bensel reports that current military research supports extensively reconfiguring CPC for improved functionality, predicting that uniforms of tomorrow's armies will be substantially different in concept and design.

Johnson and Kobrick demonstrate that, even in a thermoneutral environment, CPC significantly impairs overall sensorimotor task performance (two-handed fine dexterity), degrades rifle shot hit probability, and slows visual vigilance detection of targets by personnel on sentry duty.

Caldwell, Caldwell, and Salter report data from helicopter pilots during flight maneuvers in simulators or actual in-flight investigations. In outlining implications of CPC's thermal burden on helicopter pilots, they describe how heat stress combined with increased task loading associated with wearing CPC increases pilot errors, dramatically shortens flight endurance times, and creates difficulties for pilots staying hydrated while flying. The addition of liquid- or air-cooled microclimate vests significantly increases flight tolerance and offers promise in maintaining acceptable flight performance.

In studies of marines, Williams, Englund, Sucec, and Overson examine effects of exercise consisting of moderate marching rates while carrying heavy backpacks. Beyond the clumsiness and visual restrictions of wearing CPC, the authors find impairments in simple cognitive task performance in the form of longer reaction times, slower work rates, longer responses or lapses, and less accuracy at cognitive tasks.

Headley, Hudgens, and Cunningham review three field research programs that assess capabilities of military teams and larger units while garbed in CPC during war-game scenarios. Although most missions were accomplished, these studies dramatically illustrate the increased time demands associated with working in CPC. They also demonstrate how high ambient temperatures and increased work loads degrade combat efficiency and mission endurance when personnel wear CPC.

Ramirez portrays the contributions of behavioral science data documenting performance in CPC for operations research models. She presents a task taxonomy illustrating that some military tasks take as much as three times longer to complete when performed by personnel in CPC. Such taxonomies and predictive modeling are used by battlefield operational planners, designers of protective clothing and equipment, and test evaluators for selecting proposals for protective techniques that will promote mission success on the battlefield.

Stokes and Banderet delineate other psychological effects attributable to chemical or biological warfare threats. When personnel make decisions under ambiguous conditions and high stress, they underestimate controllable familiar events and overestimate the risk of unfamiliar, seemingly uncontrollable threats. These human tendencies influence soldier expectations of the chemical battlefield and their needs for training. They also suggest revisions in military training philosophy for operating in CPC.

The concerns outlined in this special issue of *Military Psychology* have parallels for civilian applications as well. The research findings and proposed solutions in this issue should help workers who require protection against exposure to toxic chemicals and hazardous materials, as in chemical manufacturing, hazardous waste disposal, and environmental cleanup of chemical and hazardous spills. Other workers include fire, police, and rescue squads, who may respond to emergency situations involving release of chemicals due to industrial accidents or terrorist actions.

ACKNOWLEDGMENTS

The editors of this issue and the authors of the individual articles dedicate this special issue to the many hard-working soldiers, sailors, marines, and airmen who so graciously participated as volunteers in the many experiments, studies, and field tests described in these articles. It is due to their dedication to duty and willingness to endure the inconveniences of having electrodes, rectal thermometers, biological sensors, wires, and other instrumentation affixed to them for long hours in often uncomfortable environmental conditions that the data reported here could be collected. Because of their belief that we might succeed in making things a bit safer or easier for those who follow us in the military ranks, we are able to report these findings on CPC.

Gerald P. Krueger
Louis E. Banderet
Guest Editors

MILITARY PSYCHOLOGY, *9*(4), 255–286

Effects of Chemical Protective Clothing on Military Performance: A Review of the Issues

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This review in this special issue of *Military Psychology* on the effects of chemical protective clothing (CPC) on military performance provides a historical perspective on continued anxieties over likely use of battlefield chemical–biological weapons and summarizes significant concerns of military personnel wearing CPC in training and combat. This review describes psychophysiological stresses such protective ensembles have on personnel and how these affect military performance, and it summarizes major military psychological research programs on the effects of wearing CPC. This article reviews what is known about wearing CPC, describes future CPC developments, and identifies domains for improved military training with CPC.

MEDICAL AND PSYCHOLOGICAL EFFECTS OF C–B WEAPONS

There are many medical, physiological and psychological reactions from exposure to chemical–biological (C–B) weapons. Many bio-warfare agents and most chemical weapons are designed to interfere with functioning of the nervous system and to disrupt normal control of vital organ systems that sustain life. For example, the more common chemical war nerve agents involve organophosphate compounds,

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similar to insecticides, that inhibit cholinesterase enzymes throughout the body. Because cholinesterase hydrolyzes acetylcholine wherever liberated, this inhibition results in excessive concentrations of acetylcholine at various sites—from the endings of parasympathetic nerves to smooth muscles of the iris, ciliary body, bronchi, gastrointestinal tract, bladder, and blood vessels; to secretory glands of the respiratory tract; and to endings of the sympathetic nerves to sweat glands (Newhouse, 1987; Simmons et al., 1989). Exposure to large amounts of nerve agent may lead to loss of muscle control, twitching, paralysis, unconsciousness, convulsions, coma, and even death. The most common cause of death after acute exposure is respiratory arrest. Death may occur within minutes or take several hours.

In terms of psychological functioning, moderate but nonlethal exposure to nerve agent produces severe impairment in cognition, vigilance, memory, and language. Acute intoxication produces confusion, drowsiness, and difficulty in concentration (Newhouse, 1987). These impairments make it difficult to continue to perform many soldier tasks. Effects on cognition may persist after only a slight exposure. Performance improvement appears to correlate with the body's regeneration of acetylcholinesterase, usually requiring several months.

Neuropsychological testing (Newhouse, 1987) reveals that chronic exposure to organophosphates significantly impairs higher mental functions requiring use of the frontal lobes, particularly the left lobe. Organophosphate poisoning selectively impairs memory of recently learned information, and this impairment is likely related to cholinergic involvement in memory processes. The effects include defects in long-term memory, visual searching, and response alteration—effects similar to those caused by a frontal lobotomy. In chronically exposed individuals, speed of task performance and overall cognitive efficiency also declines. Persistent visual impairments are reported in workers poisoned with anticholinesterase insecticides, and acute poisoning impairs oculomotor function. Poisoning with nerve agents may also cause psychiatric disturbances such as depression.

Use of C–B weapons results not only in large numbers of physical casualties on the battlefield but in many psychological casualties as well. Concern over the mere threat that C–B weapons might be used raises battlefield anxiety of combatants and can produce a level of fear disproportionate to that evoked by countless alternative conventional battlefield means of killing or maiming, such as with guns, artillery, and bombs. Such anxieties can create large numbers of psychological stress casualties contributing to unit ineffectiveness on the battlefield and combat losses. Such adverse emotions may also cause posttraumatic stress disorders after combat ceases.

DEVELOPMENT OF COUNTERMEASURES FOR THE COMBAT THEATER

Modern military forces recognize that C–B weapons can be the attention-getting equivalent of *a poor country's nuclear weapons.* Such weapons can be counteracted, however, and concerned nations prepare their forces to preserve their health and safety against C–B warfare. Military medical research continues to develop biochemical and biological prophylactics and treatment antidotes as matériel development pursues countermeasures such as protective respiratory masks, protective uniforms, vehicles with positive pressurized crew compartments, threat alarm systems, and equipment decontamination measures. These countermeasures involve significant development and procurement costs; they also raise many practical safety implications of military operational use and maintenance of such systems.

Fearing chemical battlefield readiness of Soviet forces, western military forces increased research programs in the 1980s to prepare to fight on a chemical battlefield. In the United States, matériel development programs progressed at a moderate pace, but those directed at human performance issues moved along briskly. U.S. military medical research laboratories devoted considerable research to medical prophylaxis and searched for treatment drugs and antidotes to chemical poisoning. However, there were safety concerns about testing in humans because the drugs and antidotes of choice involve the central nervous system. There was also a hesitancy to require human research participants to do significant physical exercise garbed in heavy chemical protective clothing (CPC) to evaluate military task performance in simulated chemical battlefield conditions—concerns of placing participants at risk of severe heat illness or injury, even in moderate weather. Several behaviorally based research and test programs prevailed (Banderet et al., 1992; H. L. Taylor & Orlansky, 1993). Many critical issues related to operating while wearing CPC were identified and addressed, and several such findings are summarized in this review article.

THE THREAT OF C–B WARFARE

Although biological warfare was used centuries ago by the Romans and was used in the 14th century by the Tartars, who catapulted plague-infected bodies into cities under siege (Hewish, 1997), military forces have made scant use of biological warfare in modern times. The more recent innovation of chemical warfare dates to 1914 when the French used tear gas against unprotected German forces, who in turn introduced chlorine and phosgene in 1915 and mustard gas in 1917 against the British, who sustained 14,000 casualties in 3 months (Hewish, 1997). Many World War I soldiers were grotesquely injured or died in gas war trenches in France and Russia; Russia's gas casualties exceeded half a million, including 50,000 fatalities (Westerhoff, 1980).

In 1925, many countries signed a Geneva Protocol prohibiting first use of chemical and bacteriological weapons. However, during the 1930s, several countries, notably Germany, encouraged chemists to develop chemical weapons as a by-product of insecticide research and production. By World War II, Germany and other military powers stockpiled huge caches of chemicals, but probably due to fear of in-kind retaliation, chemical weapons were not used in World War II. After the war, Germany's organophosphorus arsenal fell into Russian hands, and for the next 50 years, military forces relegated C–B warfare efforts to relatively quiet development programs for future battlefields.

Since World War II, C–B weapons have been employed several times on a relatively small scale. In the 1970s, the Vietnamese used chemicals and "yellow rain" biological agents in Cambodian jungles, the Soviets used chemicals in Afghanistan (U.S. Department of State, 1980), Iraq used sulfur mustard and other chemicals in the Iran–Iraq conflict (1979–1980), and Iraq used chemicals in 1980—this time against its own people, the northern Kurds (Stuteville, 1997).

There have been periodic threats to use chemical weapons on a grand scale. In the 1970s, the Warsaw Pact possessed huge stockpiles of chemical weapons (mostly soman, cyanide, and mustard gas), and Soviet chemical warfare teams openly conducted extensive training in gas warfare tactics. Such readiness for large scale C–B warfare was underscored in the Persian Gulf War of 1991, as Iraq threatened to use chemicals (sarin) and biologicals (anthrax spores) against coalition forces and possibly against neighboring cities in Saudi Arabia and Israel (Begley, Barry, & Hager, 1991). By January 1991, Saudi Arabia had predug 50,000 graves planned for burying civilian (noncombatant) casualties expected to succumb to Iraqi chemical poisoning from anticipated rocket attacks on Saudi cities or aerosols drifting from the battlefields (Kaplan, 1991).

Although Iraq did not unleash such chemicals, and the battles were ultimately short, many U.S. military personnel may have been exposed to chemicals during the March 1991 destruction of Iraqi weapon stockpiles (mostly sarin) near Khamisiyah, Iraq (Stuteville, 1997). The U.S. government continues to investigate whether exposures to chemical agents may have contributed to the so-called Gulf War illnesses experienced by many U.S. military veterans of that encounter. Exposure of soldiers to multiple chemical and environmental stressors may be linked to psychophysiological illnesses that manifest in symptomatology such as disabling fatigue, insomnia, malaise, joint and muscle pains, skin sores, hair loss, and gastrointestinal and respiratory difficulties (Brown & Priest, 1996). Others assert that U.S. military personnel were exposed to Iraqi chemical warfare from Scud missiles, artillery, and aircraft (Stuteville, 1997).

PUBLIC CONCERN

Open, frank, public news of existent military chemical stockpiles, proliferation of chemical or biological weaponry, and periodic "saber-rattling" threats to use such weapons amplify world public concerns over the enormity of what someday could be a horrific chemical or biological calamity. Unprotected civilian populations fear they may be deliberately attacked by chemical and biological weapons or inadvertently by aerosol warfare agents drifting into populated areas from a battlefield. Disastrous incidents like the one in 1984 at a chemical factory in Bhopal, India, which killed over 2,000 people and sickened countless others, sensitized citizenry to the lethal potential of such chemical compounds. In 1995, terrorist attacks on the Tokyo subway, and news media discussion of possible use of nerve agents in terrorist disruptions of public gatherings like the 1992 and 1996 Olympics, heightened public fears of the possibility of future major chemical or biological incidents. Public fears over such chemical incidents have become almost visceral. News of recent advances in genetic technologies (Dando, 1997) suggests use of future biological weapons with unprecedented insidiousness and specificity is possible. Moreover, the mass media and expert sources remind the public that the United States may not be adequately prepared or trained to defend itself against chemical or biological warfare (Beal, 1997).

THE U.N. CHEMICAL WEAPONS CONVENTION

The U.N. Chemical Weapons Convention was signed in Paris by 130 of 190 U.N. member nations in January 1993, promising to ban development, production, acquisition, stockpiling, and use of chemical weapons. Thirty-one additional nations subsequently signed this arms control agreement. Seventy-three nations, including the United States, ratified this global treaty, which took effect in April 1997. The Chemical Weapons Convention provides that countries can and should develop effective protective measures to serve as deterrents to those who would consider using weapons of mass destruction. Despite such treaties, 20 to 30 countries, most of which did not sign the U.N. treaty, currently have programs for research and development of chemical weapons; a number of them also stockpile chemical arsenals (Hewish, 1997; Pearson, 1994).

This important multilateral arms control treaty stresses mutual inspection and verification procedures. After ratification, it allows 10 years for destruction of stockpiles of chemical weapons and production facilities. It is public knowledge that armies are busy destroying thousands of old containers of chemical weapons in South Pacific island furnaces, Utah, and in former Soviet proving grounds.

CHEMICAL AND BIOLOGICAL WEAPONS

Biological Weapons

More than 60 biological agents have potential to form the basis of weapons. They are of two classes: (a) living organisms such as bacteria, viruses, rickettsiae, and fungi; and (b) poisonous products or protein toxins produced by living organisms. Biological agents can be dispersed through the air, placed in food and water supplies, or even introduced into crops to affect the food production chain. The most practical method of initiating infection in biological warfare is through dispersal of agents as minute, airborne particles (aerosols) over a target where they may be inhaled. An aerosol may be effective for some time after delivery because it will be deposited on clothing, equipment, and soil. When clothing is used later, or dust is stirred up, personnel may be subjected to a secondary aerosol. Agents may use portals of entry into the body other than the respiratory tract. Individuals may be infected by ingestion of contaminated food or water or even by direct contact with the skin or mucous membranes through abraded or broken skin (Craig, 1988). The most toxic substance is the botulinum toxin that, when inhaled, will cause progressive muscular paralysis leading to asphyxiation and death (Hewish, 1997).

Chemical Weapons

There are four types of chemical weapons: (a) nerve agents (the G-series compounds tabun, sarin, and soman, together with V-series VX, VE, VG, VM, and VS); (b) blood agents such as hydrogen cyanide and cyanogen chloride; (c) blister agents (vesicants), including sulfur mustard (HD), nitrogen mustard, and lewisite; and (d) choking or incapacitating agents, such as chlorine and phosgene (Craig, 1988; Hewish, 1997). As with biologicals, chemical war agents can be dispersed in several different ways including vapors, liquids, or aerosols.

CONSEQUENCES OF PERSONAL PROTECTION FROM C–B WARFARE AGENTS

CPC

The clothing system. Future battlefields may involve both chemical and biological threats, but in this article, we refer primarily to the chemical threat. Thus, we describe the clothing and combinations of protective uniform ensembles as CPC. For most military forces, CPC is designed to protect against a wide variety of chemicals, but it will protect against many biological and radiological agents as well. To protect themselves from battlefield C–B threats, military personnel generally wear (a) a gas mask with air purifying respirator to filter the air they breathe; (b) a rubberized protective hood that covers the head and shoulders; (c) heavy, bulky, thick textile overgarments (trousers and overcoat) impregnated with a charcoal lining; (d) rubber protective gloves; and (e) rubber overboots for the feet. Aerosol and liquid forms of chemical or airborne biological agents and radioactive particles are kept out of the wearer's eyes and respiratory system by the full facial protective gas mask. Offending chemicals are generally kept off the head, limbs, and any portions of skin via the protective hood, suit of overgarment clothing, and boots. All items are worn over the standard issue military utility uniform (Bensel, 1997/this issue).

Civilian applications. This review describes concerns military personnel have about CPC and their behavior and military task performance while wearing CPC. However, descriptions here are relevant to civilian applications for police, fire, and rescue crews; workers engaged in destruction of military chemical stockpiles; emergency response hazardous materials teams that clean up spills; or chemical manufacturers and tank truck drivers who often wear CPC when they handle or deliver hazardous chemicals and materials (J. S. Johnson & Anderson, 1990a, 1990b).

Protective postures. The CPC ensemble provides maximum protection when it is worn with all components: head cover, gas mask, rubber gloves, two-piece overgarment uniform (zipped shut or buttoned up to the neck), and overboots. On battlefields that are not contaminated, but where there is a likely chemical threat, unexposed soldiers generally wear the protective clothing partially open (overcoat partially unbuttoned without gloves or overboots) to ensure more air circulation and freedom of movement and to allow quickly zipping the ensemble closed for maximum protection when attacked. These alternative wear configurations, each providing increased levels of protection against various C–B threat situations, are categorized in the U.S. military as Mission-Oriented Protective Posture (MOPP) Levels I through IV and are categorized in NATO as Individual Protective Equipment codes red, blue, black, and so forth.

The more enclosing and protective the clothing ensemble is, the more cumbersome the suit can be, and the more pronounced CPC's impact on certain kinds of performance (e.g., tactile and visual). CPC overgarments and equipment somewhat restrict limb movement and impede tactile, visual, auditory, and olfactory functioning. When worn at the MOPP IV level, CPC becomes an encapsulated microenvironment that retains body heat of soldiers wearing such clothing, thus increasing risk of heat stress when they work in high ambient temperatures.

Establishing familiarity and confidence. Because many soldiers lack detailed familiarity with chemical or biological weapons, it is essential they understand that the CPC issued to them will protect against chemicals on the battlefield. This will do much to reduce fear, anxiety, and adverse reactions to CPC. Although familiarization training while wearing CPC varies widely in military units of all countries, most military forces effectively accomplish sufficient orientation through classroom didactic training, which usually includes photos of gruesome chemical wounds from past wars or industrial chemical accidents. Students are assured that CPC, if used correctly, will protect them. Practical exercises usually include donning a gas mask and visiting a small building filled with vapors of tear gas. This demonstration helps recruits gain familiarity and confidence that the mask will protect them from a visible agent in the air. Since the early 1980s, the U.S. Army has conducted live nerve agent decontamination training for chemical specialists in a controlled setting (Fatkin & Hudgens, 1994; Gourley, 1997).

Thermal burden. A serious concern for those who wear CPC is the thermal burden such clothing adds to a person working in the full ensemble, especially in moderately warm to hot ambient environments. The thick textile material of CPC for most military forces severely limits evaporation of body sweat through the uniform because most suits are impregnated with an absorbent charcoal lining, permitting little evaporation. Consequently, CPC hampers the natural ability of the body to thermoregulate, leading to fluid and electrolyte losses (Armstrong, Szlyk, DeLuca, Sils, & Hubbard, 1992) and increased heat stress in direct relation to severity of ambient heat conditions and level of physical work (Blewett, Redmond, Popp, Harrah, & Banderet, 1992). Conditions do not have to be unreasonably warm to present risk of heat stress. Work generates body heat that must be dissipated through the protective suit. Thus, the harder and longer the work, the more heat must be dissipated and the greater the risk of heat stress. The CPC is also stressful in other ways; even in a cool environment, wearing CPC results in unfavorable subjective reactions and adverse physiological changes (Muza, Banderet, & Forte, 1996; White, Hodous, & Vercruyssen, 1991).

In high ambient temperatures, a soldier can work encapsulated in CPC for a few hours or less (Giovoni & Goldman, 1972; Goldman, 1963; Gonzalez & Stroschein, 1992; Kobrick, Johnson, & McMenemy, 1988; McLellan, 1993; Pandolf, Stroschein, Drolet, Gonzalez, & Sawka, 1986; White et al., 1991). Researchers have recorded work endurance in CPC on the order of 1 to 2 hr in most field tests in hot environments (Headley, Hudgens, & Cunningham, 1997/this issue), up to 5 to 6 hr in some laboratory studies (Thornton & Caldwell, 1993), and upward of 11 hr in a moderate ambient temperature (Glumm, 1988; Williams, Englund, Sucec, & Overson, 1997/this issue). If appropriate work–rest cycles are adhered to, allowing a 5- to 15-min rest during each hour of work, endurance can be significantly extended (Bishop, Pieroni, Smith, & Constable, 1991; Gonzalez & Stroschein, 1992). Work tolerance or endurance "stay time" before heat stress becomes unbearable and the participant either stops working or succumbs to heat illness depends on ambient temperature conditions, solar load, humidity, and effective wind (Montain, Sawka, Cadarette, Quigley, & McKay, 1994). Also of critical importance are level of physical fitness, anthropomorphic characteristics (Armstrong et al., 1991), and heat acclimatization of participants as well as workload and work–rest ratio (Bishop et al., 1991; Bishop, Smith, Ray, Beaird, & Smith, 1994; Cortili, Mognoni, & Saibene, 1996; Goldman, 1963; Pandolf et al., 1986). Predictive computer models, incorporating many of these variables, often provide insights into thermoregulatory response of the soldier for varied ambient, uniform, and physical workload situations (Gonzalez & Stroschein, 1992; Pandolf et al., 1987).

Based on 30 years of biophysical, physiological, and behavioral data collection, the staff at the U.S. Army Research Institute of Environmental Medicine prepared information tables providing guidance on how to avoid heat stress casualties when working in CPC in hot environments. This guidance for work–rest cycles and water consumption was successfully used by American forces during operations in Southwest Asian deserts (Glenn et al., 1990) and in Somalia (Modrow et al., 1992).

CPC in cold environments. If the ambient temperature conditions are cool, many thermal limitations of CPC are reduced. In a study of wearing CPC in –10 °C, Rissanen and Rintamaki (1997) examined the effects of impermeable rubber suits and semipermeable charcoal-impregnated suits with cold weather underwear. Both types of CPC could be used for long periods in cold conditions at moderate workload without marked whole-body heat debt or heat load. However, peripheral parts of the body (e.g., fingers) underwent rapid and severe cooling during rest periods. The semipermeable suit resulted in higher body heat storage and faster rewarming of extremities during work than the impermeable suit.

Tolerance for work. There is evidence that some test participants who worked in CPC in warm environments voluntarily quit working or simply withdrew from experiments before they exceeded medical safety criteria for heavy work or onset of heat illness. We observed this in U.S. Army field tests cited by Headley et al. (1997/this issue). Reasons for "quitting the test" included heat stress, which made test participants averse to wearing CPC for long periods of time, but often other physiological and psychological reasons shortened their endurance to field test conditions. During interviews after the tests, some soldiers in tanks, armored personnel carriers, and other crew-served weapons complained of headaches, nausea, extreme hunger, discomfort, and hassles associated with the study (including wearing a rectal thermometer, electrodes, and wires affixed to their bodies). Some participants indicated simply that they had "outlasted" most of the other competitors and therefore saw no benefit in continuing.

Such has been the case in laboratory experiments as well. In one MOPP IV study, a simulated artillery fire direction center in high heat (91 °F [33 °C], 61% relative humidity [RH]), some female soldier participants were withdrawn from the experiment before onset of substantial hyperthermia. Reasons for withdrawal included fainting, incoherent responses to questions, exhaustion, or a request by the participant to terminate (Fine, 1987). These reasons for withdrawal were similar to those cited by male soldiers who anticipated quitting as volunteers in field tests.

Metabolic cost of working in CPC. Patton, Murphy, Bidwell, Mello, and Harp (1995) evaluated metabolic costs of performing various military tasks while wearing CPC (MOPP IV level) versus doing the same tasks while wearing only the utility uniform. The U.S. Army's battle dress uniform worn underneath the CPC weighed 3.7 kg. The CPC overgarment, gloves, overboots, and M17 gas mask added another 6.6 kg. The weight of the CPC and the hobbling effect caused by the bulky clothing contributed to marked increases in energy cost, especially for tasks requiring mobility across a distance. When mobility was required to perform a task, the effect of CPC increased, with the greatest increases in oxygen uptake for tasks requiring continuous mobility (e.g., load carriage). Patton et al. found that, for tasks ranging in intensity from 10% to 80% of maximal oxygen uptake, MOPP IV significantly increased oxygen uptake in 29 of 42 tasks. Increases for men were from 7% to 26%, whereas in 23 of 36 tasks for women, increases were 5% to 29%.

Restriction of body movement. The CPC uniform generally restricts certain body movements, particularly angular movements about the joints of the body (Bensel, 1997/this issue). The CPC used by the U.S. military can restrict head flexion as much as 20° in the ventral–dorsal plane and lateral rotation of the head by as much as 40° to 50° (Bensel, 1997/this issue; Bensel, Teixeira, & Kaplan, 1992). Such restrictions of head movements, principally caused by the gas mask, limit a soldier's normal visual scan; more pronounced head movements are required to view the environment and to localize sound. Frequent infantry activities like walking, running, dodging, and jumping are more cumbersome in CPC, akin to performing while wearing overstuffed snowpants with bulky overboots.

Impaired manual dexterity, tactile sensations, and psychomotor coordination. Unfortunately, CPC also degrades manual dexterity, psychomotor coordination, and performance of many activities accomplished with the hands (Kobrick et al., 1988). The rubber gloves distort normal tactile feel for tools, equipment controls, keysets, and grip handles. Finger dexterity can be affected as much as 30%, depending on the thickness of the gloves, with thicker (0.44 mm) gloves requiring more time to accomplish simple keying tasks accurately (Bensel, 1993). Finger dexterity and visual–motor coordination worsen slightly by wearing the rubber handwear and mask (Bensel, 1997/this issue; Bensel, Teixeira, & Kaplan, 1987); pilots, keenly aware of the importance of tactile feel for flight controls, are reluctant to wear the bulky gloves when flying an aircraft.

Effects of the Gas Mask

Resistance to breathing. Gas masks impose breathing resistance (inspiratory and expiratory) for their wearers (Kelly, Yeager, Sucec, Englund, & Smith, 1987), with the typical modern military gas mask producing a four-fold increase in resistance to breathing (Muza, 1986). Attempting to breathe normally with the gas mask and its filters can lead to breathing distress, hyperventilation, shortness of breath, tremors, and claustrophobic reactions (Muza, 1986; Muza et al., 1996). Such problems are also commonplace in the civilian workforce, for example, in firefighting, where respirators are worn (Morgan, 1983). Psychological anxiety encountered with such breathing resistance can be decreased through familiarity training with the gas mask. However, performance of tasks requiring high aerobic power (e.g., running) is hindered greatly by breathing resistance because this factor becomes more critical under high workload conditions (A. T. Johnson & Berlin, 1974; Muza, 1986; van de Linde, 1988). Thus, more time is usually required to perform certain tasks when the gas mask is worn.

Speech intelligibility and communications quality. Wearing the gas mask and hood hinder speech intelligibility because they degrade speech transmission and reception (Bensel et al., 1992; Garinther & Hodge, 1987; Muza, 1986). Bensel et al. demonstrated that listeners, unencumbered by gas mask or hood, only achieved a mean score of 65% on the Modified Rhyme Test when the speaker they were listening to wore either an M17 or an M40 gas mask. This index was less than the level of acceptability of voice communication of 75% (Bensel, 1997/this issue). This finding is of concern because even the two voice resonators in the M40 facepiece, compared to one in the M17, do not produce quality speech.

Restricted and optically distorted visual fields. Gas masks often restrict visibility by blocking part of the visual field (Bensel et al., 1992; Harrah, 1985; McAlister & Buckingham, 1993; Muza, 1986). The newer M40 gas mask offers some advantages over the standard M17 it will replace, but both respirators restrict vision significantly in the temporal and super-nasal regions of the visual field compared to viewing with no mask (Bensel, 1997/this issue). More head-turning movements are needed to see objects and receive information in the peripheral visual field, a condition more likely during night operations. Protective eye-lens viewing ports affixed to the gas mask are usually a flat sturdy plastic that contribute to visual parallax and distortion of images during target detection and identification. Also, some regions in the pilot's visual field are obscured by the mask, a degradation of vision that can be critical during flight for helicopter pilots reading instrument panel indicators or looking for hazards like telephone wires while flying at low level.

There is also a practical problem of seeing through the gas mask when the lenses fog up due to accumulation of perspiration inside the mask, creating a severe problem for a soldier who must maintain good visual contact. The moisture is not easily alleviated without breaking the mask-to-face seal to let the accumulation drain out the bottom of the mask. However, in a crew-served weapon system, conditioned air is normally circulated inside the gas mask and minimizes this problem.

Prescription lenses. Soldiers who normally wear prescription eye wear should use prescription lenses inside the gas mask. Getting corrective lens inserts for a gas mask has been a significant logistical problem, and even during field studies of CPC, wearers of eye glasses frequently do not have insert lenses for their gas masks (Blewett et al., 1992; Carter & Cammermeyer, 1989). Using a gas mask with insert lenses can be problematic because the lenses are usually secured in a metal frame affixed on the lens well of the mask, and it is difficult to maintain the tilt angle of the lenses for comfortable visual acuity (McAlister & Buckingham, 1993), especially during visually demanding tasks such as firing a rifle (Harrah, McMahon, Stemann, & Kirven, 1991).

Various military occupational specialties (e.g., aviation) involve tasks requiring exceptional visual functioning, even if it is achieved via use of prescription lenses. It is difficult to design an aviator's gas mask that fits close to the face while providing sufficient eye relief behind gas mask-mounted optical insert lenses to accommodate needed visual corrections. As a result, experiments with mask frontsert lenses were initiated (Wildzunas, 1995). Because about 20% to 30% of U.S. Army aviators require optical correction (Wildzunas, 1995), the U.S. Army equipped its attack helicopter crews with extended-wear contact lenses so these pilots could have corrective lenses compatible with the aviator's gas mask and helmet-mounted display sighting systems; unfortunately, some could not be fitted adequately with contact lenses because of presbyopia or astigmatism (Lattimore & Cornum, 1992).

Compatibility with night vision goggles and optical sighting systems. The optical sighting systems, including infrared and thermal sights, and night scopes of most crew-served weapons are generally incompatible with wearing a gas mask. Binocular searches for targets are easier with masks containing flat surface lenses versus curved ones (Harrah, 1984, 1985). Thus, flat surface lenses are now generally being adopted for gas masks issued to military, police, fire, and rescue personnel. However, specialized masks designed for armor or aviation crew members generally do not permit a proper sight picture through optic systems used in many vehicles because drivers, gunners, or navigators have to press the face mask to an optic sighting tube to look through it. If the person is also wearing prescription optic inserts inside the gas mask, it is difficult to obtain a proper sight picture through the prescriptive lens, the protective eye ports for the gas mask, and, subsequently, the optic tube.

Night vision goggles provide exceptional capability to perform most military tasks under low-level illumination at night. Night vision goggles, which are strapped on the face or onto a helmet-mounted sighting system, are not compatible with wearing a gas mask. They are sometimes worn by helicopter pilots, but obtaining suitable visual information from the collage of wearing an aviator's gas mask, helmet, night vision goggles, protective armor, and survival vests dramatically burden a pilot who must still see the instruments and the terrain outside to fly safely.

Other Concerns

Personnel identification in CPC. When all combatants are garbed in CPC at the MOPP IV level, it is difficult to identify who is who, largely because distinguishing or identifying marks such as hair, skin color, stature, and body shape are not visible or are disguised, and familiar voices are distorted. Many military units therefore resort to supplemental identifying markings on the ensemble and to hand signals to ensure visual feedback in intraunit communication.

Eating and drinking. Although exploratory research has devised a means to supply soft food via tube feeding through the mask, it is not a popular alternative to waiting for the battle to stop, doffing the mask in a safe place, and eating solid food. Few, if any, tube feeding systems have been fielded. Drinking fluids, however, is critical to maintaining hydration during extended wearing of CPC. Avoiding contaminants while drinking through the mask is difficult at best, but a new developmental prototype drinking tube arrangement with snap-over connectors to affix to 2-qt water canteens protects both the mask and the water supply from contamination (Szlyk et al., 1989), and these are being fielded.

Loss of olfactory cues. The CPC mask and filter system alter olfactory cues, the "smells of the battlefield." Soldiers use these to detect odors indicating the status of diesel or electric motors and other equipment, to identify battlefield smokes and obscurants, and to appreciate the culinary delights of field food.

Elimination of bodily waste. A subject not often written about is the need to eliminate bodily waste while wearing CPC. Although it is difficult to eat and drink through the mask, a regularized drinking regimen to protect against heat stress requires periodic urination. If troops are fortunate to have enough to eat, eventually they need to eliminate solid waste as well. CPC systems, containing zippers and rear flaps, are not designed well for easy waste elimination without risk of compromising their protective value during chemical exposure (Cardello, Darsch, Fitzgerald, Gleason, & Teixeira, 1991). Faced with such biological needs during training scenarios in the presence of a simulated threat, most soldiers simply unzip to void without fear of consequences. However, combatants exposed to an imminent chemical threat are likely to seek collective shelter (inside a vehicle or building) and only there doff portions of the clothing to meet this need. Adequate provisions for special male and female hygiene are not accounted for in the present design of CPC.

Sleep. It is difficult to sleep comfortably while wearing a gas mask. Sleeping posture has to be carefully selected, and when sleeping on one's side, the somewhat rigid structure of the hard rubber mask may be dislodged from its tight fit on the wearer's face. If the seal of the mask is compromised, the protective value of wearing the mask is sacrificed. Lieberman, Mays, Shukitt-Hale, Chinn, and Tharion (1996) found soldiers who slept in an M40 mask tolerated it for most of the night, but measurements with wrist activity monitors indicated soldiers took longer and found it more difficult to fall asleep when wearing the mask. Their sleep was significantly disturbed, with length of waking time increased from 25 to 86 min per night, and the number of awakenings from 8 to 20. Protection provided by the masks varied among participants; some soldiers were protected throughout the night, but others were only protected intermittently (Lieberman et al., 1996). On the other hand, soldiers commonly mention that, when they sleep on the ground or in armored vehicles, CPC provides a certain amount of cushioning and warmth in cold weather.

Decontamination and donning and doffing of CPC. A significant concern when wearing CPC is how to properly don and doff the clothing. If advance warning of chemical attacks is given, combatants don CPC to the MOPP II or III level; when the danger is imminent, they button (or zip) up to MOPP IV. If they have not had advance warning, and are not partially garbed when they encounter C–B agents, a scramble to don the CPC without getting contaminants into the mask and suit is likely.

Likewise, after a CPC suit has repelled chemical agents, especially liquids, for a period of time, doffing the suit without contaminating oneself can be problematic. One must first find a safe, uncontaminated location in which to take off the CPC, such as a collective protection shelter established for the purpose. Otherwise, a soldier may have to be within a closed vehicle, where there is increased risk of contaminating that vehicle, or may move some distance away and stand in an open, chemical-free area. Then, one can carefully scrape solid agent (e.g., mustard) off the suit to partially decontaminate it, and then doff the outfit, hopefully without getting chemical residue on oneself or on one's clean equipment or clothing. Work at the U.S. Army Human Engineering Laboratory documented how difficult this chore can be (Harrah, Bruno, & Weaver, 1990), requiring laborious decontamination procedures for each piece of exposed clothing, equipment, and mask. However, if the logistics supply system provides sufficient replacement CPC during a battle, troops can forgo some decontamination procedures and simply exchange these items and return to duty.

Stowage of CPC. When troops are not wearing CPC, a practical matter often overlooked is that there are usually not enough convenient safe places to stow and transport such clothing. This is as true for vehicle crews, who never have enough room inside tanks or armored personnel carriers, as it is for foot soldiers, who often must carry the CPC or wait to be supplied from vehicles coming from the rear echelon.

Effects on Military Performance and Other Indexes

The articles in this publication were selected because they cover a range of behavioral and performance concerns regarding CPC. Their methodologies are representative of various naturalistic, laboratory, and field approaches to the study of CPC issues. Articles in this special issue describe general functional performance (Bensel), rifle marksmanship (R. F. Johnson & Kobrick), helicopter pilot performance (J. L. Caldwell, Caldwell, & Salter), cognitive performance after physical exercise (Williams et al.), extensive assessment of military crew, team, and unit (ranging from squad to battalion in size) operations in the field (Headley et al.), and predictive modeling of performance (Ramirez). They also provide insights into more general psychological concerns on the chemical battlefield (Stokes & Banderet).

Sensorimotor and psychomotor performance. The scientific literature includes performance data from participants who wore CPC and were tested on sensorimotor, psychomotor, or performance tasks. Researchers subjected participants to different ambient temperature conditions ranging from slightly cool environments, to conditions at approximately room temperature (a kind of thermoneutral state), and to conditions of very high heat and humidity. As indicated earlier, high heat and high humidity limited endurance times, whereas, in the absence of risks of heat stress at the more moderate temperature conditions, investigators were able to focus on factoring out the effects CPC has on performance.

An illustrative study investigated several performance tasks including one of the most basic soldier skills, rifle marksmanship (Kobrick et al., 1988). R. F. Johnson and Kobrick (1997/this issue) indicate that wearing CPC in a thermoneutral environment (55 °F [~13 °C], 30% RH) almost immediately impaired overall sensorimotor task performance. Arm–hand steadiness degraded 30%; two-handed gross dexterity, 35% to 40%; two-handed fine dexterity, 55%; single-hand fine dexterity, 30%; and hit probability for rifle firing at pop-up targets, 18% to 22%. Simulated sentry duty in CPC decreased vigilance performance (speed of detection dropped almost 55% after 1.5 hr of testing) and degraded rifle marksmanship. Such performances were stable and appeared related to the encumbering characteristics of CPC, performances that were not degraded over 6 hr of thermoneutral testing. During 2 hr of heat exposure (95 °F [35 °C], 60% RH) and testing, wearing CPC likewise degraded sensory and psychomotor performance in a fashion similar to thermoneutral conditions and similarly degraded the accuracy of rifle firing by 19% to 22%. Neither ambient heat nor the time spent on the task increased the effects when rifle firing was performed for as long as 2 hr. Most participants opted not to continue testing past 2 hr, whereas others were withdrawn for medical safety reasons (R. F. Johnson & Kobrick, 1997/this issue).

Another military task that requires exceptional sensorimotor and psychomotor performance is piloting fixed or rotary wing aircraft. J. L. Caldwell et al. (1997/this issue) studied performance of 16 army helicopter pilots wearing the latest design in aviator's chemical protective flight suit while flying a high-fidelity helicopter simulator under controlled ambient temperature and humidity conditions. However, due to cumulative heat stress, one third of the pilots did not complete a 6-hr flight scenario in 95 °F (35 °C), 50% RH conditions. Pilots who completed this flight scenario exhibited at least one significant increase in pilot control error in every flight maneuver tested under the 95 °F (35 °C) condition. Additionally, most aviators became dehydrated, partially because of difficulties in getting enough water from the drinking tube in the mask. Flight performance and physiological data indicated heat stress; the increased task loading caused by wearing CPC increased pilot errors. Yet, J. L. Caldwell et al. observed that environmental conditions tested in these studies are less threatening than many of those encountered in actual military flight operations.

Such demonstrations of the impact of CPC and resultant body heat buildup in warm flight environments prompted the military aviation community to vigorously pursue development of cooling systems for aviators who must fly while wearing CPC. Both liquid- and air-cooled microclimate vests showed promise in maintaining an adequate physiological state and significantly increased endurance time. Although flight performance data are less clear, such cooling systems permit pilots to maintain adequate flight performance in most maneuvers. In select cases, aviators actually exhibit improved flight control performance (Thornton, Caldwell, Guardiani, & Pearson, 1992).

Cognitive performance. Several behavioral studies of soldiers performing cognitive tasks while wearing CPC purport to have examined cognitive performance as it might be affected by CPC. However, these studies generally were deficient in experimental design because they did not adequately rule out visual and psychomotor impairments due to the configuration of masks, gloves, and other equipment; they did not pretrain participants sufficiently on the cognitive tests of interest; they did not properly account for circadian rhythm variations in analysis of time series performance data; or they did not acquire sufficient data because of loss of participants to early onset of heat stress.

Kelly, Ryman, et al. (1987) showed that wearing the gas mask decreased speed and accuracy in simple reaction time tasks, but no differences were attributed to the mask on more complex tasks (e.g., reaction time, visual vigilance, and logical reasoning). In contrast, Caretti (1997) tested various cognitive performances (visual input) during 10-hr sessions and found no difference between cognitive performance for the condition of M40 gas mask and no gas mask (comfortable room temperatures with no exercise). Rauch and Tharion (1987) investigated the effects of wearing various combinations of mask and gloves on speed and accuracy of solving cognitive problems at 72 °F (22 °C). They found the rate of problem solving slowed but not the accuracy. Rauch and Tharion attributed the impairment to changes in manual dexterity and not to cognitive processing.

Fine and Kobrick (1987) employed a series of simulated artillery fire direction center tasks to assess problem solving of sedentary male soldiers wearing CPC during 7-hr work periods on 4 successive days with different temperature and humidity conditions. After 4 to 5 hr in the heat with CPC, the average cognitive performance of the participants began to deteriorate markedly. After 6 hr in the heat, productivity of the participants on a self-paced map plotting task diminished by 40% from control conditions; accuracy of plotting was not markedly affected. By the end of 7 hr of heat exposure, increases in average percentage of error on investigator-paced tasks ranged from 17% to 23% more than control conditions. Virtually all errors were omissions.

A series of studies examined the effects of moderate exercise in CPC on cognitive performance. Williams et al. (1997/this issue) studied 72 marines experienced with CPC who performed lengthy road marches while carrying loads, 50% of their body weights, over 18- to 24-mile (29–39 km) distances. The marines wore CPC for 11 hr (with hood and gloves removed for a short meal break after 5 hr) following a 24-hr combined physical and mental work session without sleep. A battery of cognitive tests was administered. These studies simultaneously examined interactive effects of moderate physical exercise, an antihistamine, mild sleep deprivation, and the type of uniform the participants wore (CPC or standard marine utility uniform), making it difficult to specify the variance attributed to each. Williams et al., however, found the marines wearing CPC exhibited simple cognitive impairment such as longer reaction times, slightly impaired accuracy, a slower work rate, more lapses, and more excessively long responses. Williams et al. emphasized that wearing CPC produces moderate cognitive decrements beyond those attributable solely to physical limitations produced by clumsiness in wearing rubber butyl gloves or to visual restrictions of the mask in viewing target stimuli, concluding that sleep-deprived soldiers wearing CPC take longer to do tasks, have trouble maintaining attention to the tasks, and have less accurate performance due to less efficient cognitive processing.

Operational performance of teams. As described earlier, wearing CPC while performing military tasks limits soldiers' dexterity, mobility, communications, and task endurance. Headley et al. (1997/this issue) reviewed three military research programs involving field studies of soldiers wearing CPC in hot environments during extended operational military work scenarios, often 24 hr or longer, which included night operations. These "team studies" (military program titles DO49, P^2NBC^2, and CANE) included 2-person teams performing cooperative tasks (e.g., disassembling a tank engine for a DO49 project) while wearing CPC; about 20 different P^2NBC^2-controlled scenarios with specific crew operated military systems (e.g., 3–4 crew members in tanks, self-propelled howitzers, and armored personnel carriers); five large-scale CANE tests, including a study of 40-person platoon-sized military units performing infantry operations (i.e., CANE I in 1986); and large free-play operations of hundreds of soldiers (i.e., CANE IIB in 1989) in tests of full battalion-sized scenarios on simulated battlefields.

These field experiments demonstrated most standard military tasks can be performed satisfactorily, but extra time is required to perform them in CPC. High ambient temperatures and high workloads are especially detrimental to endurance in CPC. Many measures of combat effectiveness degraded in MOPP IV. These included difficulty in locating and reporting enemy positions; poorly timed and executed battle synchronization; engaging enemy forces at closer ranges than desirable; firing fewer primary weapons; lengthy time intervals to alternate battle positions; and general degradation in command, control, and communications.

These field studies, especially those with many soldiers carrying out military task scenarios on large stretches of terrain, were exploratory and descriptive in nature (Headley et al., 1997/this issue). They involved determining operational principles of practical importance to the military community, and some were noteworthy field demonstrations, but trustworthy scientific extrapolation of findings from some of these studies is difficult. Some studies could be classified as indelicate experiments (Sinaiko & Belden, 1965) because they incorporated many tenets of rigorous experimental design, but like many large man–machine system experiments (Parsons, 1972), they also involved numerous uncontrolled variables inherent in military field operations. As pointed out by H. L. Taylor and Orlansky (1993) and by Montgomery (1987), frequently good baselines for performance data were not established before testing, and in some tests, the presentation of experimental conditions was not counterbalanced.

Notwithstanding such cautions, the overriding lessons of these studies are that (a) much of the present CPC used by the U.S. military must be redesigned with more attention to human engineering factors, and (b) repetitious realistic training in CPC ensembles is essential to sustain performance on a C–B contaminated battlefield. Lessons learned, in particular, called for more realistic training for military leaders at all levels to enhance understanding of how individual human behavior changes, especially on a unit basis when large numbers of soldiers are all wearing CPC.

Modeling the effects of CPC on military performance (operations research). Military planners, combat developers, and tacticians continually use operations research models to prepare for threats envisioned on the next battlefield. Combat models involve specialties on offensive or defensive military operations and include projections of requirements concerning personnel, training, human factors, survivability, and safety analyses. Developing predictive models of soldier behavior on a dynamic battlefield is one of the biggest challenges of operations research. Ramirez (1997/this issue) points out what a daunting task it is to predict the outcome of many time-and task-linked sequential activities on a fluid, dynamic battlefield; it is particularly tough when the combatants wear CPC intermittently. Useful, valid predictive models must rely on reliable, behavioral, computer-accessible databases that can be used to foresee impacts of the battle theater on soldier performance.

Ramirez (1997/this issue) describes U.S. Air Force and U.S. Army efforts to develop behavioral models of soldier performance while wearing CPC in simulated chemical environments. Models to predict the times required to accomplish various military tasks and the debilitating psychological effects of wearing CPC are complex constructions and are challenging to modify or verify. Early modeling work concerned predictions of the "time to complete or perform tasks," either by individuals or by small military units and was then extrapolated to larger units. Air force and army studies determined that degradation in task performance varied with crew experience. Performance of routine military tasks required 50% to 70% more time when wearing MOPP IV; CPC impeded performance of tasks requiring manual dexterity because of the encumbrance of the bulky CPC. The models also estimated the impact of dramatic heat effects on performance and on the expectation of heat-related casualties (exhaustion or stroke) attributable to sustained CPC operations in hot environments with little food and water.

Obtaining suitable quantitative data on large military units is a difficult and expensive proposition. Eventually, the U.S. military, primarily the U.S. Army, collected such data (Driskell, Guy, Saunders, & Wheeler, 1992; Headley et al., 1997/this issue; H. L. Taylor & Orlansky, 1993) to support computerized analyses and predictive modeling of unit performance in various chemical battlefield scenarios. From these and other data, Ramirez (1997/this issue) devised a task taxonomy. Some military tasks do not require increased time to perform while wearing CPC, whereas others take three times as long. Tasks affected so dramatically by CPC are usually modified by the soldier or not completed at all.

Such modeling by operations researchers predicts individual soldier and military unit performance, offers computer tools and cost-effective methods to CPC designers for evaluating new designs, enables equipment testers to perform better evaluations, and provides battlefield planners with tactical insights for deployment of forces.

Psychological issues. Stokes and Banderet (1997/this issue) suggest that, in combat with C–B weapons, there will be many more psychological stress casualties than actual C–B injuries. This prediction reflects the adverse impact of fears and anxieties troops experience in dealing with the threat of a C–B contaminated battlefield. In part, such anxieties are attributable to the insidious, ambiguous nature of many chemical and biological agents that prompt fears of dying a hideous death on the battlefield.

Stokes and Banderet (1997/this issue) describe possible battlefield responses characterized by the psychological overreactions of hyperventilation, claustrophobia, gas-mask phobia, compulsive practices, or obsessive concern with decontamination, congregating in safe or collective protection areas, finding excuses never to come out or let others into a safe space, and hoarding or stealing protective items. They also describe underreactions to the chemical threat such as psychological denial, fatalism, rationalization, or intellectualization. All prevent troops from taking adaptive actions or enacting useful countermeasures. Muza et al. (1996) demonstrated that the CPC evokes predictable psychological reactions such as anxiety, feelings of not getting enough air, perceptions of abnormal breathing, and stress. For combatants, such concerns can be fueled by their lack of confidence in the CPC and their inability to use it properly for protection (Blewett et al., 1992; Carter & Cammermeyer, 1989). B. J. Taylor (1993) emphasized the benefits of coping strategies, relaxation techniques, good leadership, and training to decrease or prevent extreme fear and many adverse reactions. Education, training, and experience with CPC can go a long way toward reducing these fears (Fatkin & Hudgens, 1994; B. J. Taylor, 1993).

Soldiers who spend lengthy training sessions garbed in CPC occasionally report loneliness, a distorted sense of time passage, and alterations in distance estimates. For example, armor crews in MOPP IV approaching channelizing terrain "bunch up their vehicles" so they are five or six vehicles abreast waiting their turn to go through narrow terrain gaps. This makes them a concentrated target; risk of enemy aerial or artillery attack is greatly increased. A National Training Center (Ft. Irwin, CA) cadre sergeant stated: "Every group coming here for training does the same thing in MOPP IV, they bunch up their vehicles, ... it seems that they just want to feel closer together despite the obvious risks" (Krueger, interview of NTC cadre, March 1987).

DISCUSSION AND CONCLUSIONS

Much is known about the effects of CPC, for example, its effects on the soldier's physiology, ambulatory mobility, manual dexterity, and sensorimotor and psychomotor performance. Considerable data describe the degrading effects of CPC on visibility, communications, and respiration. Most suggestions and concerns call for significant improvements in human engineering design of the encapsulating microenvironment of CPC. Many of those will have to come as developments in future technologies now being explored become mature enough for implementation. Several biomechanical restrictions imposed by CPC might be lessened somewhat if protective-level design criteria could be made slightly less stringent when applied to select military scenarios (e.g., quick offense vs. slow defense) or to job functional specialties (e.g., aviators, armor crewmen, infantrymen, etc.). This might lead to adopting several alternative inventory CPC systems. Advancements in multimedia training technology may offer significant strides in training troops to have confidence in their CPC and equipment. Operational doctrine for use of CPC at the functional unit level might be improved if it permitted local commanders more flexibility in determining what level of protectiveness (i.e., MOPP level) their troops would assume during operations. Each of these is briefly outlined in turn.

Human Engineering System's View

It is essential that improved CPC, with its myriad components, be designed and evaluated as a soldier protective system. This approach includes accounting for the interactions of CPC with different environments, crucial equipment interfaces such as optical sighting systems, and critical military operational tasks. Bensel's (1994) outline of CPC and equipment characteristics, the physiological and mechanical effects it imposes, and her commentary on soldier differences, influences of leadership, cohesion, and training, provide an important systems design perspective. This perspective is also nicely described and reinforced by B. J. Taylor (1993). A. T. Johnson, Grove, and Weiss (1993) offer an equipment performance rating scheme for gas masks to aid trade-off decisions, an approach that could be adapted to evaluate other CPC components such as gloves, boots, and overgarments. Multinational cooperative programs are now prevalent to address these important issues.

Gas Mask

The gas mask is implicated as the primary CPC item responsible for negative psychological reactions among soldiers and for much of the operational performance degradation (Bensel, 1994, 1997/this issue). Design changes should include reduced resistance to breathing; improved visibility through the mask; an easy system for use with prescription lenses; an antifogging system; enhanced speech intelligibility through innovative use of electronic technologies; a better interface of the mask with other equipment, especially optic sights; and easier access to food and drink.

Uniforms

Extensive redesign of the CPC uniform is required to improve gross body movement and fine psychomotor control while wearing the suit. Lightweight protective materials that impose less heat burden also should be integrated with personal, wearable cooling devices or a source of cool, conditioned air from a vehicle. Other CPC improvements would include thinner handwear to provide adequate tactile feel and features to permit easier donning and doffing, compatibility with sleeping, and a convenient means of voiding excess perspiration during work or in excessive heat. Special attention will need to be given to waste elimination and personal hygiene so that male and female soldiers can utilize these uniforms and capabilities rapidly, conveniently, and in a manner acceptable to all users (Cardello et al., 1991).

Lightweight CPC

Developmental programs of NATO forces and other western nations aim to devise suitable lightweight CPC uniforms that present less risk of heat stress. McLellan (1996) and McLellan, Bell, and Dix (1994) described Canadian efforts to evaluate Canadian- and French-designed protective clothing ensembles worn directly over the skin or over underpants and shirt, thus eliminating wearing the normal utility uniform under CPC. In a similar program, Levine, Quigley, Latzka, Cadarette, and Kolka (1993) described one of a series of tests to evaluate U.S.-designed chemical protective undergarments. Such developments undoubtedly will find their way into the design of an integrated protective ensemble that might offer modular clothing and equipment systems for combat ground troops. Cadarette, Quigley, McKay, Kolka, and Sawka (1993) evaluated the first components of such a system and published physiological data. The four branches of the U.S. military presently collaborate on a joint service lightweight integrated suit (JSLIST) technology program to produce lighter and less bulky protective uniforms (Bomalaski, Hengst, & Constable, 1993). Using recent improvements in carbon absorber technology, the Australians claim their C–B suit, developed to provide protection against liquid and vapor chemical agents, significantly reduces heat strain in tropical environments (Amos & Hansen, 1997).

Personal Cooling Systems

Military laboratories have experimented with personal microclimate cooling systems worn under the CPC (e.g., Pandolf et al., 1987). Banta and Braun (1992) used ice vests to reduce heat strain of helicopter pilots based on navy carriers in high heat environments. Ice cooling is generally less effective than air or liquid cooling, and although the wearer can move about without being tethered, it may be suitable only for short-term work because it necessitates repeated access to ice (Derion & Pozos, 1993).

More frequently, liquid- or air-cooled vests are worn under CPC (Bomalaski, Chen, & Constable, 1995; Fonseca, 1981; Masadi, Kinney, & Blackwell, 1991; Pandolf et al., 1987; Pimental, Cosimini, Sawka, & Wenger, 1987; Shapiro et al., 1982; Vallerand, Michas, Frim, & Ackles, 1991). Both systems have benefits and drawbacks: Air cooling can increase tolerance time fourfold, whereas recirculation of high-temperature air provides little cooling and may be dangerous. Air cooling is less efficient than liquid cooling because specific heat of air is lower. Liquid cooling is effective in reducing heat strain at light to moderate workloads when applied on large body surfaces (such as on the thighs during lower body exercise), but if overcooling results with a liquid-cooled system, discomfort may occur due to cutaneous vasoconstriction. Also, liquid-cooled systems are heavy, require excessive maintenance, and pinching or bending of tubes can result in interrupted coolant flow.

Liquid- and air-cooled technologies are especially promising for those who ride in crew-served armored vehicles, helicopters, or planes with access to suitable power sources. Cadarette, Pimental, Levell, Bogart, and Sawka (1986) demonstrated the utility of air-cooled microclimate vests and ventilated facepieces for armor personnel in desert and tropic environments, and Thornton et al. (1992) and J. L. Caldwell et al. (1997/this issue) explored liquid- and air-cooled microclimate cooling systems for use by helicopter pilots. For the ground soldier, Masadi et al. (1991) evaluated liquid-cooled vests for which the coolant was chilled by ice packs carried on the back. They also found that the use of batteries for electric-powered, portable air-conditioning systems adds much weight to an infantryman's backpack. Although such self-contained systems provide substantial body cooling, the heat reduction is not sufficient under highly stressful conditions (Caderette et al., 1993; Constable, 1993).

It may therefore be necessary to select the best cooling system for crew-served vehicles and other situations on a case-by-case basis. For infantry "ground-pounders" and other personnel who do not have access to a power source, much more design work needs to be done on portable cooling systems, including lightweight batteries or alternate sources of power for microclimate cooling systems carried on the back. Such improvements to cooling systems may increase comfort, allowing soldiers to perform more efficiently and for longer durations in toxic chemical environments.

Adopting More Than One CPC System

The U.S. and other military forces train for deployment to combat theaters anywhere in the world. These theaters vary dramatically in terms of climatic conditions, enemy to be engaged, and type of military operation. J. A. Caldwell (1992) surveyed 148 army personnel after the Gulf War's Operation Desert Storm to describe compatibility of wearing CPC and logistical problems associated with CPC in desert combat. Helicopter pilots frequently commented that CPC was incompatible with night vision goggles or with head-up displays (8%), was bulky or heavy (6%), unavailable in the quantities required or its expected usefulness was exceeded (5%), presented mask-related problems (4%), and that overboots were incompatible with flying (4%). From this survey, it is evident the CPC was somewhat incompatible with the mission and special equipment associated with flying a helicopter. No doubt similar stories could be told by armor and mechanized infantry forces.

The many constraints CPC imposes seem in part attributable to a logistical scheme of providing a single standardized design of CPC that offers maximum personal protection (i.e., the thickness of the protective uniform itself) to all combatants. U.S. military field tests of CPC (e.g., P^2NBC^2) often set goals for participants to wear CPC for 3 or more days at the MOPP IV level. Such testing told much about what soldiers can and cannot do in studies of endurance. However, with the exception of being holed up in lengthy defensive postures, as exemplified by the standoff in Dien Bien Phu, Vietnam in 1954, in future conflicts, it is not likely that our forces will be wearing "maximal protection CPC" (MOPP IV) for several days at a time. Given the enormous distances covered in an open desert by today's fast moving armor and air forces (e.g., the 100-hr war of Desert Storm), it is also not likely any military force could keep an open battlefield continuously bathed in chemical agents long enough to prohibit vehicle-mounted forces from navigating their way out of danger.

Perhaps, therefore, the military supply system should provide a variety of CPC ensembles, including clothing that is lighter in weight, which may provide less absolute protection but which might allow greater personal mobility for fast movement on a fluid battlefield. If multiple CPC uniform systems were adopted, it might permit better optimization of CPC's characteristics to the military mission (environment and threat), better matching of CPC with the soldier and the tasks to perform (e.g., Special Forces on a ground reconnaissance mission versus a driver in a vehicle or a pilot in a high-performance aircraft). Although the strategy of having several design sets of CPC will increase developmental costs, inventory requirements, and distribution efforts for the military, the U.S. military already issues numerous other uniforms and clothing systems and inventories several different versions of the gas mask for infantry, aviators, and tankers. It seems to make sense in the case of the entire CPC ensemble as well.

Improved Simulation and Realistic Training for Combat Readiness

Because military units experience a high turnover rate of personnel, troops should train frequently in CPC on common military tasks, and as well in larger scale team scenarios in which they practice working together, to ensure troops are adequately trained to use their CPC and other protective equipment. Because CPC usually encumbers movement, breathing, heat exchange, and mission performance (especially during heavy physical work in high ambient temperatures), it is important that training be conducted under realistic conditions for maximal transfer of training. Lack of experience with the gas mask and CPC are good predictors of soldiers who will most likely experience difficulties or terminate during a field training exercise. Soldiers with corrected vision who do not have prescription inserts for their gas masks are more vulnerable to aversive symptoms when wearing CPC (Blewett et al., 1992; Carter & Cammermeyer, 1989). Therefore, the logistic system should catch up to their specific needs for individual prescription eyewear.

Intensive training to do critical tasks in CPC can promote confidence, reduce adverse emotions, and better prepare all forces to fight successfully on a contaminated battlefield. In order for training to be more realistic for maximum benefits to result, the use of expert multimedia training technology could reduce some adverse emotional effects and even some performance impairments associated with CPC. Today's multimedia training technologies provide many low-cost, but sophisticated, high-technology media training alternatives that can be used to present interesting information and scenarios to convey militarily relevant information in ways that troops would enjoy and learn. Many such multimedia training systems are interactive, and the level of complexity can be adjusted to suit the needs, providing troops with effective training to respond to combat situations characterized with more alternatives and fewer static options. Many U.S. Army field training exercises and facilities presently show such greater sophistication and tactical play as they deliberately practice and teach lessons that are best learned in training (e.g., National Training Center) and not during combat (Gourley, 1997).

Adaptive Doctrine for Lowest Feasible Protective Posture

Military doctrine should support training and fighting whenever possible at the lowest safe-protective posture level (MOPP) so that adverse effects of CPC can be minimized. Because not all enemies have the same chemical capabilities, the tactical situation determines the likelihood chemicals will be used, environmental conditions influence chemical agent effectiveness, and different mission requirements dictate how much CPC will compromise soldier performance. In any event, employment of CPC in combat is a calculated risk.

The greatest performance-limiting factor in CPC is excessive buildup of body temperature especially during work in hot environments. If more training with lower protective postures is to occur, military doctrine must be developed to guide and specify conditions under which it is appropriate and to establish how decisions are to be made with regard to changes toward more or less restrictive protective posture. The decision logic must be communicated so that forces involved understand the ground rules at both the centralized command level and at the unit level, where local protective conditions might differ from those of other units. These concepts should be practiced so that troops learn to operate confidently and comfortably in training, and in combat situations, at lower levels of protective posture (e.g., MOPP I–III).

CONCLUDING REMARKS

This special issue of *Military Psychology,* describing the effects of CPC on military performance, presents much information relevant to these challenges and should provide a clearer understanding of the adverse effects (physiological, psychological, sensory, performance) as well as tradeoffs involving CPC for different military tasks and missions. With this information, risk analyses for doctrine developers and planners will be more quantitative, and the costs and benefits of different equipment, personnel, and mission alternatives under consideration can be specified with greater certainty.

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Soldier Performance and Functionality: Impact of Chemical Protective Clothing

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This article describes the components of the chemical protective uniform used by U.S. Army infantry and other ground troops and presents research on the effects of the clothing on soldier performance. The clothing has been found to impose not only a thermal burden but also a mechanical burden. Respirators restrict the visual field and affect speech intelligibility. Body movements are limited by the clothing; manual dexterity capabilities and psychomotor performance can also be negatively impacted. In addition, wearing the clothing may induce psychological stress. Symptoms include breathing distress, tremors, and claustrophobia. Efforts described here are underway to address performance issues during development of new protective uniforms. Research needed to address psychological issues is also suggested.

Civilian workers requiring protection against exposure to toxic chemicals, such as those involved in chemical manufacture or hazardous waste disposal, are commonly outfitted in respirators and protective clothing that completely encapsulate the body. Typically, the clothing is made of materials that are impermeable to liquid penetration for protection of the body from chemical agent poisoning. Thus, the clothing imposes a heat load on the wearer because the impermeability also restricts sweat from evaporating outward (Paull & Rosenthal, 1987). To avoid heat illness, the protective clothing is removed during frequent rest breaks taken in nontoxic areas. While workers are on some jobs, the protective outfit may be augmented by a cooling device to remove body heat, such as a vest containing ice worn close to the skin.

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Some U.S. Army personnel (e.g., munitions plant workers) have assignments similar to those of civilians who work around toxic chemicals. These personnel, like their civilian counterparts, wear respirators and impermeable clothing and use ice-filled vests to alleviate the build up of body heat between rest breaks taken in nontoxic areas.

Most other U.S. Army personnel have jobs more typical of the military functions performed in combat operations. For them, toxic chemicals are a battlefield threat rather than the focus of their daily work. Armored vehicle and attack helicopter crews are expected to engage their targets while garbed in chemical protective uniforms to shield them in the event of chemical attacks, and ground troops are expected to be likewise prepared while carrying out their myriad battlefield assignments. There may not be a safe, nontoxic area in which to take a work break, remove hot, protective clothing, and rest. Furthermore, personal cooling devices are not widely available to the military. All these factors make military operations in chemically contaminated environments very challenging.

In this article, I first describe the chemical protective uniform used by the U.S. Army and summarize the physiological implications of wearing the uniform. I then present studies of the effects that the protective items have on the soldier's performance and research conducted into psychological reactions associated with use of the clothing. Finally, I address ways for improving the performance and functionality of soldiers wearing chemical protective clothing (CPC).

ARMY CPC

Depending on the particular armored vehicles and aircraft they are in, tankers and aircrews may have a vest that circulates cooled air around the upper torso, a capability as yet unavailable to ground troops such as infantrymen. The CPC used by Army tankers and aircrews also differs somewhat in design from that used by ground troops. However, the basic items worn by all Army personnel include a full-face respirator (i.e., a mask), hood, coat and trousers, overboots, and handwear. The versions of this clothing in widest use are those designed for infantry and other ground troops.

Respirators

There are presently two types of full-face respirators worn by U.S. Army ground soldiers. One, designated the M17, has been an issued item for many years, and the other, the M40, is gradually being phased in as its replacement. Both respirators are pictured in Figure 1. The eye-to-lens distance on the two respirators is approximately 0.6 cm (Harrah, 1985). However, lens height is 1.0 cm less and lens width is 0.5 cm less on the M17 than on the M40. Design of the devices for filtering

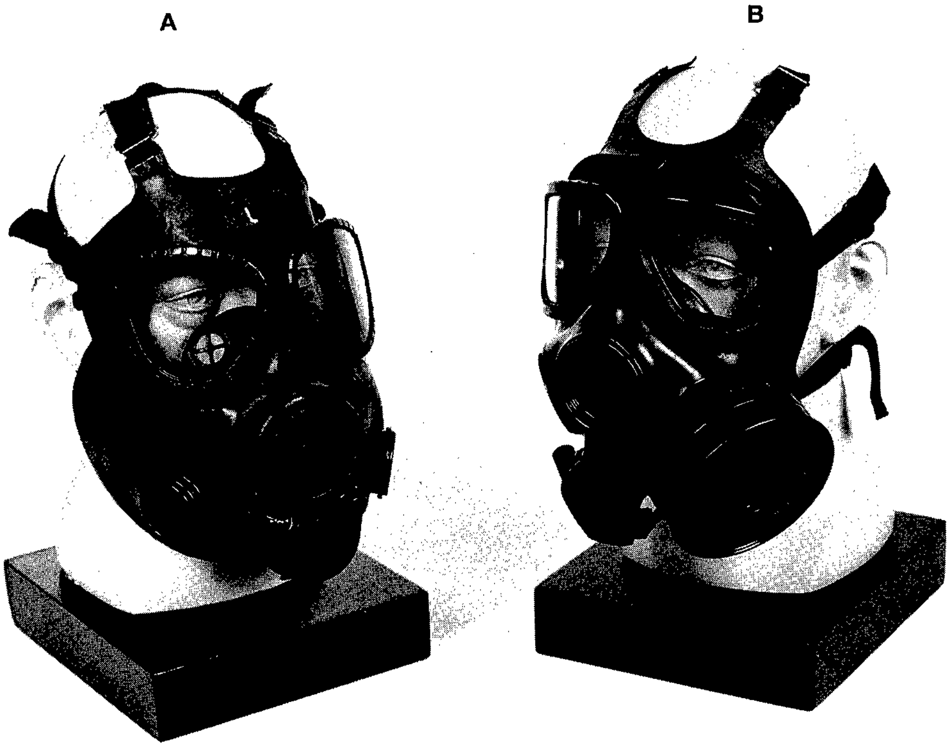

FIGURE 1 Two types of respirators: (a) M17 respirator and (b) M40 respirator.

incoming air also differs for the two respirators. On the M17, the filtering devices are embedded in the facepiece. On the M40, the filtering materials are in a metal canister, external to the respirator, which attaches to the air intake valve. To aid in verbal communication, the M40 has two voice resonators in the oronasal area of the facepiece; in contrast, the M17 has one. Both respirators have a hood, made of nylon cloth coated with butyl rubber, which covers the head and the shoulders and is attached to the facepiece.

Handwear

The ground soldier's protective handwear, made of butyl rubber, consists of five-fingered gloves with long gauntlets to cover the wrists and lower arms. The gloves are close fitting, but not skintight, and each is in the shape of a relaxed hand. The nominal thickness of the handwear is 0.64 mm. These gloves are worn over thin (0.02 mm), cotton gloves, which aid in the absorption of sweat.

Overboots

The protective overboots worn by ground troops are made of vinyl and resemble galoshes. These boots are designed to be worn over the soldier's leather combat boots.

Coat and Trousers

The soldier's protective coat and trousers are made of layers of permeable materials. The outermost layer is a nylon–cotton twill. Under this is a laminate of charcoal-impregnated foam and nylon tricot. The coat extends down over the hips, overlapping the trousers. The arm, neck, and leg openings are sealed tightly around the body, and the front of the coat zips up to the neck. A soldier outfitted in the chemical protective uniform is pictured in Figure 2.

PHYSIOLOGICAL EFFECTS OF CPC

In a toxic chemical environment, protection of the soldier's skin is achieved by encapsulating the body in the uniform described previously. Some of the materials used, such as butyl rubber, are impermeable to liquids. Other materials, such as those used in the protective coat and trousers, are permeable but have high thermal insulation, or high resistance to the passage of heat, and low moisture vapor transmission, or high resistance to the passage of sweat. Therefore, protective clothing use severely constrains the normal heat-dissipating mechanisms of the body, particularly sweat evaporation (Martin & Goldman, 1972). Depending on environmental conditions and work rates, a soldier can become a heat casualty within 30 to 90 min (Joy & Goldman, 1968). Resistance to breathing encountered when using a respirator can also be a physiological burden, especially during heavy work (Raven, Dodson, & Davis, 1979).

Avoiding Heat Casualties

Because of the high levels and prolonged periods of physical activity required of infantrymen, and the lack of a cooling device for them, much of the research into the physiological effects of wearing protective clothing has focused on infantry soldiers. From this research have come guidelines for use by military commanders in the field in order to avoid heat casualties among their troops. There are guidelines for manipulating work–rest cycles, with rest periods increasing in frequency and in duration as ambient temperatures and work rates increase (Department of the U.S. Army, 1993).

FIGURE 2 Chemical protective uniform used by U.S. Army infantry and other ground troops, with insets of the chemical protective gloves and overboots.

A second set of guidelines is referred to under the nomenclature of Mission-Oriented Protective Posture (MOPP) levels. Employing these U.S. military guidelines, the commander determines the particular protective clothing items to be worn depending on assessment of the threat of chemical exposure. At the lowest level, MOPP I, the only two protective items worn in readiness for encountering agents are the coat and trousers. At the highest level, MOPP IV, all protective items are worn (Department of the U.S. Army, 1993).

Much of the physiological research has dealt with assessing new clothing and protective materials, particularly those for use in uniform coats and trousers, which might produce less of a heat load on the wearer. Success in this area is problematic because the material properties required to protect against exposure of the skin to chemicals are associated with high thermal insulation and low evaporative heat loss. As a result, other efforts have addressed development of personal cooling devices that might be practical for use by ground troops. This area, too, is slowed by technical limitations; battery power sources for these devices are an additional, substantial load to be carried by the already burdened soldier, and timely renewal of exhausted power or cooling elements is not practical given the logistics of military field situations.

EFFECTS OF CPC ON SOLDIER PERFORMANCE

Although physiological stress is a major concern, findings from a number of studies suggest the protective items themselves, independent of the thermal burden they represent, interfere with the execution of military tasks. Cox and Jeffers (1981) found that, when wearing CPC, U.S. Air Force ground crews required an average of 72% longer to get a plane ready for a flight than they did when wearing normal duty uniforms, even when times for rest breaks were not considered. Again considering only the time spent working, Stack and Sager (1988) reported that U.S. Marines trained in communications took 21% longer to disassemble and pack radio teletype equipment when performing the job wearing CPC than they did while wearing the regular uniform. Parker, Stearman, and Montgomery (1987) calculated increases of 30% and more in times for teams of U.S. Army personnel to perform maintenance work on tank engines and transmissions when wearing CPC.

Use of the clothing has also been associated with impairments in execution of tasks that are critical to a soldier's safety and success on the battlefield. These include rifle firing (Johnson, McMenemy, & Dauphinee, 1990), scanning a target area with binoculars (Harrah, 1985), navigating a vehicle (Blewett, Ramos, Redmond, & Fatkin, 1993), traversing on foot, particularly at night (Wick, Morrissey, & Klopcic, 1987), and hearing (Johnson & Sleeper, 1985).

These studies indicate CPC imposes not only a thermal burden but also a mechanical burden. If CPC is to be designed to lessen this burden, the negative impact that individual components of the uniform or their interactions have on performance must first be identified and quantified. Colleagues and I carried out a series of studies at the U.S. Army Natick Research, Development and Engineering Center for this purpose. The studies were designed to minimize contributions of physiologically stressful factors such as extreme temperatures, elevated activity levels, and extended work bouts. The research included testing of vision, speech intelligibility, body mobility, manual dexterity, and psychomotor coordination. Twelve participants were selected for each study from a pool of U.S. Army enlisted men.

Visual Field Testing

Perimetric measurements of the visual field made monocularly indicated that the M17 and the M40 full-face respirators restrict the visual field substantially compared with no mask (Figure 3). An analysis of variance performed on the data for each visual region yielded a significant headgear effect for all but the temporal$_1$ axis (Bensel, Teixeira, & Kaplan, 1992). The M40 respirator, now standard issue for ground troops, was tested, along with the M17, the respirator that the M40 is replacing in the Army inventory. Possibly because of the greater height and width of its lenses, the M40 offered some advantages over the M17, particularly in the temporal$_2$ and super-nasal regions of the visual field (Figure 3). Although post hoc tests revealed that both respirators restricted vision significantly in these areas relative to no mask, the restrictions imposed by the M17 were significantly greater than those imposed by the M40.

Speech Intelligibility

Wear of the respirator and hood was also found to affect speech intelligibility, as measured by the Modified Rhyme Test (House, Williams, Hecker, & Kryter, 1965). In trying to identify the monosyllabic words, listeners without mask and hood made significantly more errors when the person speaking wore a respirator and hood than when the speaker wore neither (Bensel et al., 1992). Furthermore, the listeners had a mean score of only 65% when the person speaking wore either the M40 or the M17 respirator. This score is below the level of acceptability set forth by the military for voice communication (Military Standard, MIL–STD–1472D, 1989). A score of 75% on the Modified Rhyme Test equates with minimally acceptable intelligibility, a level at which understanding of even standardized phrases is limited.

Body Mobility, Manual Dexterity, and Psychomotor Coordination

Measurements of maximum angular movements about joints of the body indicated that limitations are imposed by one or more of the chemical protective items comprising the complete ensemble (Bensel, Teixeira, & Kaplan, 1987). Data from measurements of head flexion and rotation while wearing a normal duty uniform, the protective overgarment alone, and the complete protective outfit with the M17 mask are presented in Table 1. Both head flexion and rotation were restricted in the complete outfit compared to movements in a normal duty uniform or in the overgarment alone. Simple movements were performed while wearing various

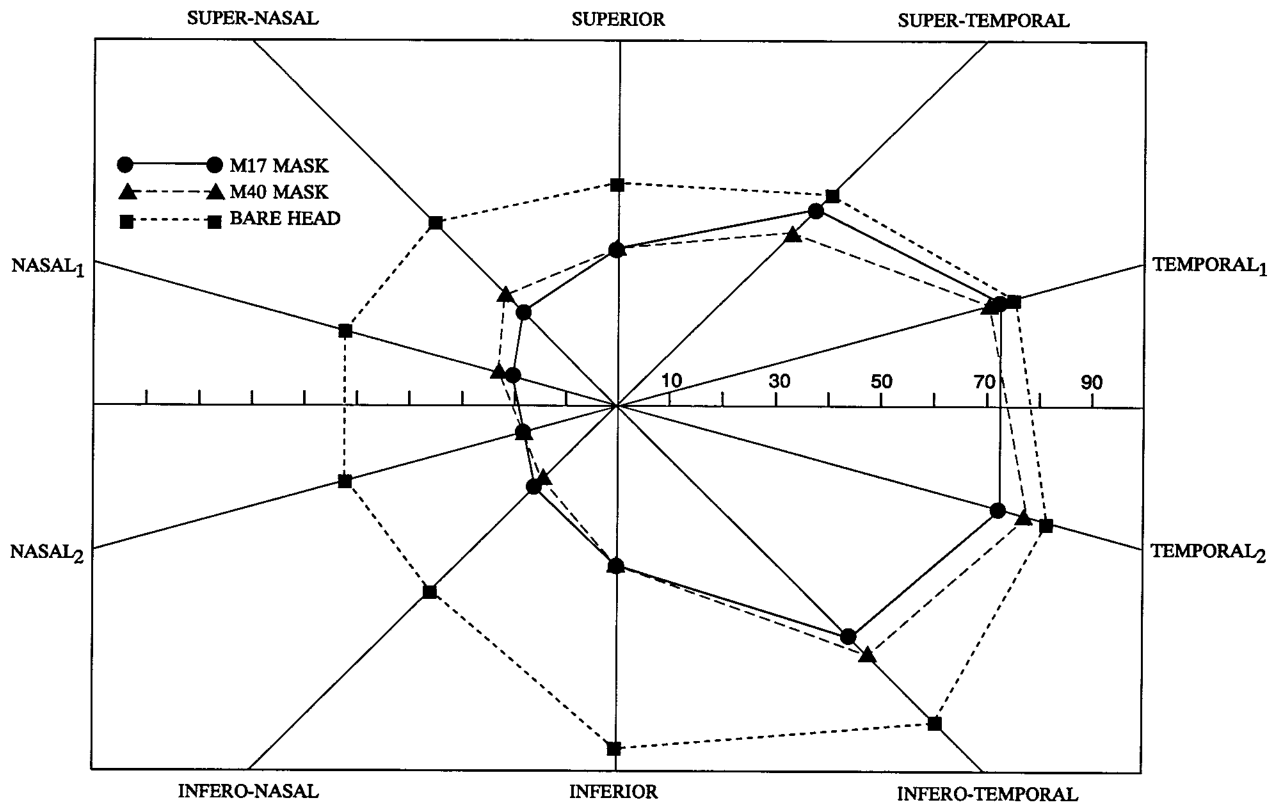

FIGURE 3 Visual field for two respirators and the bare head.

TABLE 1
Mean Scores on Tests for Three Military Clothing Configurations

	Military Clothing		
Test	*Duty Uniform*	*Chemical Protective Overgarment*	*Complete Chemical Uniform*
Ventral–Dorsal Head Flexion[a]	141_a	139_a	120_b
Lateral Head Rotation[a]	156_a	148_a	106_b
O'Connor Finger Dexterity Test[b,c]	74_a	73_a	106_b
Pursuit Rotor Time on Target[c]	104_a	$100_{a,b}$	95_b

Note. $N = 12$. Means with different subscripts were significantly different in Newman–Keuls multiple comparison tests at $p < .05$.
[a]In degrees. [b]Hines and O'Connor (1926). [c]In sec.

combinations of chemical protective items; the respirator was the item that most restricted these movements.

Time to complete a test of fine finger dexterity, the O'Connor Finger Dexterity Test (Hines & O'Connor, 1926), was also significantly longer when the complete protective outfit, including the M17 respirator, was worn compared to times recorded when the normal duty uniform or the protective overgarment alone was worn (Table 1; see also Bensel et al., 1987). The protective item contributing most to poor dexterity performance was the butyl handwear; the respirator also had an effect but to a lesser extent. The combined effect of the handwear and the headgear was greater than the sum of the effects when each was worn individually. There was a similar finding on a test of visual-motor coordination, the Pursuit Rotor (Table 1; see also Bensel et al., 1987). Time on target decreased slightly when either the respirator or the gloves were used relative to use of the overgarment alone. Wearing both the respirator and the gloves resulted in a performance decrement greater than the sum of the decrements associated with each item alone.

PSYCHOLOGICAL EFFECTS OF CPC

In addition to having a negative effect on basic performance parameters, even in the absence of thermally stressful conditions, CPC has been found to elicit negative psychological reactions, even when there is no threat of exposure to toxic chemicals. Field studies of soldiers using CPC, many conducted under the sponsorship of the U.S. Army's program on the Physiological and Psychological Effects of the NBC Environment and Sustained Operations on Systems in Combat (P^2NBC^2), have provided evidence of increased intensity of perceived symptoms and deterioration of mood (Taylor & Orlansky, 1993).

In one of these studies, three 9-man howitzer crews were to perform a 24-hr, live-fire mission in MOPP IV, and an additional crew was to carry out the same mission in normal duty uniforms (Knox, Mitchell, Edwards, & Sanders, 1989). The crew wearing the normal duty uniforms completed the mission as planned with no loss of personnel. Because of withdrawals from testing, none of the crews in MOPP IV was operational for as long as a single, 4-hr duty cycle. Only one of the 27 men using protective clothing was removed for exceeding the rectal temperature safety limit; another 12 men left the test on their own initiative (Knox et al., 1989). Using posttest responses on the Environmental Symptoms Questionnaire (ESQ; Kobrick & Sampson, 1979), Rauch et al. (1986) found that the 13 individuals who withdrew or were withdrawn from testing (i.e., the casualties) were more symptomatic than the remaining 14 men (i.e., the survivors), particularly with regard to the rated intensity of shortness of breath and headache symptoms. Furthermore, a contrast of responses on the pretest and the posttest administrations of the ESQ revealed that the survivors' symptom intensity ratings changed little over the exercise, whereas the casualties' ratings increased significantly.

In a study in which U.S. Army tank crews were to carry out a 72-hr exercise in CPC, participants were trained in stress management techniques prior to testing (Glumm, 1988; Munro et al., 1987). Relaxation techniques and strategies for maintaining situation awareness were included in the training. None of the 48 participants was removed from testing for medical reasons. However, 25 men withdrew on their own initiative, and no crew sustained operations for longer than 32 hr (Glumm, 1988). Analysis of the posttest ESQ revealed that the casualties gave the symptom of painful breathing a substantially higher rating (by 640%) than did the survivors. The casualties also reported more frequently than the survivors that the stress management strategies were not helpful (Munro et al., 1987).

Negative psychological reactions to CPC have also been observed during field exercises in which personnel were to wear the clothing for as little as 1 to 2 hr. Carter and Cammermeyer (1985) reported claustrophobia, anxiety, tremors, and other negative reactions in 69 of 100 troops in MOPP IV for a 2-hr medical care drill. Brooks, Xenakis, Ebner, and Balson (1983) reported a 20% incidence of symptoms such as hyperventilation and tremors among 70 soldiers in MOPP IV for a 1-hr medical training drill. Some of the affected individuals experienced psychological symptoms immediately after the start of the exercise, and others experienced difficulty during the later portions.

Evidence of psychological stress associated with wearing CPC is not limited to military field situations; evidence has been acquired even in an innocuous laboratory environment (Warren, Poole, & Abusamra, 1988). Warren et al. tested 12 U.S. Army enlisted men on psychomotor and cognitive tasks under laboratory conditions selected to minimize physiological stress. On each of five consecutive days, the state anxiety scale (Spielberger, Gorsuch, & Lushene, 1970) was administered immediately before the men put on the chemical protective uniform and began the tasks. After performing the tasks in the protective uniform for 2 hr, the participants again completed the scale. The posttest scores were higher than the pretest, indicating an increase in anxiety over the session.

The respirator has been implicated as the item of chemical protective gear chiefly responsible for negative psychological reactions among soldiers (Brooks et al., 1983; Carter & Cammermeyer, 1985; Munro et al., 1987; Rauch et al., 1986). Morgan (1983b) maintained that breathing resistance, restricted vision, and limited ventilation across the face—all common experiences when wearing a respirator—can produce anxiety and lead to symptoms of hyperventilation. Furthermore, according to Morgan (1983a), the hyperventilatory episodes themselves provoke anxiety. Although research into individual differences in psychological reactions to the use of respirators is limited, there is evidence that some individuals are at greater risk than others for experiencing respiratory distress and that the likelihood of negative reactions can be predicted from an individual's trait anxiety level (Morgan & Raven, 1985).

IMPROVING PERFORMANCE AND FUNCTIONALITY OF SOLDIERS

Extensive redesign of CPC is a major focus of the U.S. Army's developmental efforts already underway to outfit ground troops of the 21st century. Reduction of visual restrictions is a priority in development of a new respirator. The concepts being considered would reduce eye-to-lens distance and have curved lenses that conform to the shape of the eye. To improve speech intelligibility, each soldier would have an electronic communication device, including earphones and a microphone placed in the respirator. The handwear of the future will be thinner than that used by soldiers today and may be made of permeable materials rather than of rubber.

In the development of the new clothing, emphasis is being given to integrating lightweight chemical protective materials into clothing items that form the basis of the ground soldier's regular duty uniform, thus avoiding the need for bulky overgarments and hoods and ill-fitting overboots. The most ambitious feature of the protective uniform of the future will be the provision of a personal cooling device that the ground soldier will carry. One such device that has already been tested weighs 6.8 kg and operates for up to 4 hr, distributing filtered, ambient-temperature air to the respirator and to a vest worn under the clothing.

With personal cooling and the new protective clothing, field soldiers of the future should be able to perform their jobs more efficiently and for longer periods in toxic chemical environments. As Taylor and Orlansky (1993) pointed out in their review of studies on the effects of wearing CPC, soldiers must also train in the clothing, carrying out their job-specific assignments and chemical defense tasks, if performance decrements are to be substantially reduced. However, research is required to determine ways to improve training programs, particularly with regard to addressing the psychological implications of encapsulation in chemical protective uniforms (Bensel, 1994; Taylor & Orlansky, 1993). For example, the effectiveness of stress management techniques should be evaluated, and leadership skills that are critical to successful operations in a chemical environment should be identified. Also, little is known about individual differences in psychological reactions to using protective clothing and the most effective regimens for treating soldiers who experience negative reactions to the clothing. Efforts to improve training programs, coupled with progress in clothing development, should substantially enhance the performance and functionality of soldiers in chemical protective uniforms.

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Effects of Wearing Chemical Protective Clothing on Rifle Marksmanship and on Sensory and Psychomotor Tasks

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This article reviews and evaluates the findings of several studies on the effects of wearing chemical protective clothing (CPC) on rifle marksmanship and on selected sensory and psychomotor tasks. Task performance in the Battle Dress Uniform under thermoneutral conditions was used as a standard for comparison based on percent change to evaluate the separate and combined effects of wearing CPC, exposure to ambient heat, and test duration. The findings indicated that wearing CPC resulted in an early overall impairment of task performance but that the magnitudes of impairment did not increase progressively over time (up to 6 hr) beyond the initial impairment levels. Although wearing CPC under hot conditions caused heat stress and, thus, limited test time to less than 2 hr, it did not degrade sensory or psychomotor performance beyond that observed under thermoneutral conditions for the same time period. Wearing CPC during heat exposure did, however, degrade rifle firing accuracy during the 1st 2 hr. Tasks involved in simulated sentry duty showed that wearing CPC intensified vigilance decrements and degraded rifle marksmanship.

The possible deployment of chemical weapons in modern warfare mandates the use of chemical protective clothing (CPC). The CPC ensemble at the highest protective level (Mission-Oriented Protective Posture Level IV [MOPP IV]) in the U.S. military includes CPC jacket, trousers, overboots, gloves, and protective mask. When the MOPP IV ensemble is worn over the U.S. Army field uniform, called the Battle Dress Uniform (BDU), both body movement and sensory input are

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considerably restricted. Also, the low moisture vapor permeability of CPC limits sweat evaporation and, thus, hampers the natural ability of the body to thermoregulate. This leads to increased heat stress in direct relation to the severity of ambient heat conditions.

Recent experiences of U.S. and coalition forces wearing CPC in the heat during training and combat in the Middle East War of 1990–1991 (Desert Shield and Desert Storm) prompted considerable concern about performance capabilities of soldiers under such conditions. Because U.S. forces and their allies have a continuing role in hot regions of the Middle East and Southwest Asia, where chemical warfare may be a critical factor, accurate assessment of performance degradation due to wearing CPC under hot conditions has become a crucial requirement for effective military planning and decision making. This article reviews and interprets the results of several studies that investigated the effects of wearing MOPP IV on simulated rifle marksmanship and on performance of various sensory and psychomotor tasks relevant to typical military activities.

METHOD AND APPROACH

Measures of Change in Performance

One of the traditional methods for interpreting changes in performance due to contingent conditions is to relate those changes to the magnitude of a preceding baseline performance in the absence of those conditions. This concept can be represented as a percent change in performance as follows:

$$\text{Percent Change} = \frac{\text{New Performance} - \text{Baseline Performance}}{\text{Baseline Performance}} \times 100$$

This metric allows changes in performance to be interpreted in terms of the normal baseline capabilities of the individual.

Some investigators used this index to describe performance while dressed in CPC ("new performance") compared to performance while dressed in the BDU ("baseline performance"). For example, using a percent-change index, Johnson, McMenemy, and Dauphinee (1990) reported that soldiers' M16 rifle marksmanship accuracy was 19% poorer when they were dressed in CPC compared to their performance when dressed in BDU. Using a similar percent-change index, Draper and Lombardi (1986) found an even greater reduction of M16 rifle marksmanship accuracy in CPC (54% lower than in the BDU).

A number of studies report the effects of CPC on soldier performance using a variety of experimental conditions and measurement techniques. However, the range of different testing conditions involved and the use of nonstandardized performance measures make it difficult to generalize the results. The consistent application of an index of percent change in performance would aid in the evaluation of these disparate studies.

In an effort to organize available findings, Taylor and Orlansky (1991, 1993) used variations of the percent-change index in extensive reviews of literature on effects of wearing CPC on soldier performance, including combined-arms exercises, field studies, and laboratory investigations. They termed their modified index *percent degradation* and gave two basic formulas for its calculation: (a) percent *time* degradation (D_T), defined as the percent difference in time to complete a task while wearing CPC relative to task-completion time while wearing the BDU; and (b) percent *accuracy* degradation (D_A), defined as hits, correct answers, and so forth relative to a similar baseline. Although their overall assessment of the findings based on percent degradation was generally successful, of necessity some of their interpretations were based on interpolated estimates when raw data were unavailable.

Performance in BDU: The Standard for Comparison

Applying the percent-change index, we reviewed several studies of effects of CPC, heat exposure, and test duration on simulated rifle marksmanship and selected sensory and psychomotor tasks. We used performance while wearing the BDU for 1 to 2 hr under thermoneutral conditions as a standard baseline for comparison. We chose this baseline for the following reasons: (a) The BDU is the fundamental field duty uniform worn by U.S. Army and Marine ground troops; (b) it is lightweight and unencumbering and, thus, is reasonably close to a "non-uniform" control condition; and (c) measurements made during the first 1 to 2 hr of performance reflect the capabilities of soldiers who are still alert and motivated. This standard for comparison has the added advantage of familiarity to military planners.

Several pertinent investigations were conducted at our institute. However, most of the data came from one comprehensive study of performance capabilities on psychologically based tasks during 6 hr of exposure to heat while dressed in MOPP IV (Kobrick, Johnson, & McMenemy, 1988, 1990a, 1990b). These tasks were largely sensory, psychomotor, and marksmanship tasks and included sensory functioning, perceptual–cognitive functioning, sensorimotor skill, subjective reactions, and M16 rifle marksmanship. In this study, we assessed independently and in combination, the effects on task performance of heat exposure (95 °F [35 °C], 60% relative humidity [RH]), test duration (6 hr), and the MOPP IV CPC ensemble consisting of the BDU plus butyl rubber gloves and overboots, chemical protective overgarment (charcoal-impregnated jacket and trousers), and Model M17A1 gas mask with hood. Other data in the analysis came from related studies on the effects of CPC on speech intelligibility (Johnson & Sleeper, 1985), manual dexterity (Johnson & Sleeper, 1986), visual perimetry (Kobrick & Sleeper, 1986), M16 rifle marksmanship (Johnson et al., 1990), and simulated sentry duty performance (Johnson, 1991, 1992). All studies cited used the temperate zone BDU, as opposed to the hot-weather BDU, as the standard BDU for comparison, and only male soldiers were tested.

Proper application of the percent-change index requires a determination of whether the calculated percent change in the raw scores is a degradation or an improvement in baseline performance. For example, good "marksmanship accuracy" in BDU can be reflected by both a high score (number of targets hit) or by a low score (number of attempts to attain a tight shot group). In this article, percent-change statistics were calculated in two steps. First, the percent-change index was calculated according to the basic formula:

$$\text{Percent Change} = \frac{\text{Performance in MOPP IV} - \text{Performance in BDU}}{\text{Performance in BDU}} \times 100$$

Positive or negative signs were then assigned to the percent-change indexes based on whether they represented an improvement (+) or a degradation (–) in performance.

SOLDIER PERFORMANCE WHILE WEARING CPC

Effects of Ambient Heat and Time in CPC

Percent degradation in performance is summarized in Table 1. The first column includes 2 measures of M16 rifle marksmanship, 10 types of sensorimotor tasks, 2 types of reaction time, 11 measures of visual proficiency, and 1 measure of speech intelligibility. The second column lists group mean baseline performance in the original measurement units, that is, BDU under thermoneutral conditions (70 °F [21.1 °C], 30% RH) during the first 2 hr of a 6-hr test session. The remaining columns list percent degradation from BDU baseline performance as a function of time into the test session and ambient temperature. Note that an ambient temperature of 55 °F (12.8 °C), 30% RH was used as the thermoneutral condition for soldiers dressed in MOPP IV. This temperature, rather than 70 °F (21.1 °C), 30% RH, was used to avoid the mild heat stress usually generated by wearing the MOPP IV ensemble at 70 °F (21.1 °C), 30% RH. No data were collected beyond the 2nd hr for the 95 °F (35 °C), 60% RH condition because the cumulating heat stress at this temperature forced participants to withdraw either voluntarily or for medical safety reasons.

Table 1 shows that both measures of M16 rifle marksmanship and five measures of sensorimotor performance, including arm–hand steadiness, two-handed gross dexterity (Minnesota Rate of Manipulation and Ball-Pipe), two-handed fine dexterity (Purdue Pegboard), and one-handed fine dexterity (O'Connor Fine Finger Dexterity), were degraded significantly by wearing CPC. Regardless of the duration of exposure, all measures of visual performance (acuity, phoria, stereopsis) were unaffected by wearing CPC, including the M17A1 gas mask with hood. Speech intelligibility and tapping were slightly impaired. Impairments in sensorimotor performance appeared to be caused primarily by the bulk of the clothing itself. Neither ambient heat nor time on the task appeared to increase the severity of the effects.

The significant impairments in rifle marksmanship and sensorimotor performance (from Table 1) for the thermoneutral conditions are summarized in Figure 1.

It is clear that performance degradation in the CPC condition ranged from 20% to 56% during the first 2 hr (the 5% change in stationary target marksmanship was nonsignificant) but with little if any additional change up to 6 hr.

Table 1 shows that, with the exception of marksmanship for stationary targets, exposure to ambient heat (95 °F [35 °C], 60% RH) did not intensify performance decrements beyond those for wearing CPC alone during the first 2 hr under thermoneutral conditions (55 °F [12.8 °C], 30% RH). This finding is shown graphically in Figure 2 for the seven performance tasks impaired by wearing CPC.

Table 2 summarizes additional data on the effects of CPC. In rifle marksmanship, maintaining a tight shot group under thermoneutral conditions was not significantly impaired (similar to Table 1). However, hitting rapidly appearing pop-up targets was significantly degraded at 19%. Johnson et al. (1990) attributed these differences in proficiency to the fact that the shot group task was self-paced, whereas the pop-up target task was machine-paced, with an average intertarget occurrence interval of 1 sec. There was a marked impairment in manual dexterity (Johnson & Sleeper, 1986), ranging from 38% to 183%, with the Purdue Pegboard task being more affected than the O'Connor Fine Finger Dexterity task. Johnson and Sleeper (1986) attributed this difference to being required to manipulate three types of small objects on the Purdue Pegboard task versus only one type of small object on the O'Connor task. The only impairment on visual performance (Kobrick & Sleeper, 1986) was in the ability to detect rapidly appearing stimuli over the entire visual field due to wearing the M17A1 mask. Performance degradation on this task ranged from 25% to 28% regardless of temperature conditions. Speech intelligibility (Johnson & Sleeper, 1985) was slightly affected but only after 4 hr of heat exposure.

Vigilance and Marksmanship in CPC

In several reports on target detection and rifle marksmanship during simulated sentry duty (Johnson, 1991, 1992; Johnson & McMenemy, 1989a, 1989b), the soldier stands at a Weaponeer M16 rifle marksmanship trainer (Spartanics, Ltd.,

TABLE 1
Percent Degradation of Performance in MOPP IV Compared to Standard Performance in BDU

	Baseline Mean	*Percent Degradation*					
	70 °F (21.1 °C)	*55 °F (12.8 °C)*			*95 °F (35 °C)*		
Performance Task	*<2 Hr in BDU*	*<2 Hr*	*2.0–3.9 Hr*	*4.0–6.0 Hr*	*<2 Hr*	*2.0–3.9 Hr*	*4.0–6.0 Hr*
Marksmanship							
Weaponeer							
1 × 1 shot group[a]	6.28	*ns*	–24	–24	–22	A	A
Pop-up targets[a]	57.86	–20	–14	–18	–19	A	A
Sensorimotor							
Arm–Hand Steadiness[b]	44.45	–29	–28	–29	–30	A	A
Minnesota Rate of Manipulation[b]	36.27	–41	–39	–38	–36	A	A
Purdue Pegboard[c]	12.08	–56	–58	–57	–55	A	A
O'Connor Finger Dexterity[c]	14.93	–30	–39	–36	–32	A	A
Tapping							
One side dominant[d]	97.33	*ns*	*ns*	*ns*	*ns*	A	A
One side nondominant[d]	87.67	*ns*	*ns*	*ns*	*ns*	A	A
Two sides dominant[d]	60.93	–16	*ns*	*ns*	*ns*	A	A
Two sides nondominant[d]	50.60	*ns*	*ns*	*ns*	*ns*	A	A
Ball-pipe[c]	67.00	–26	–23	–28	–26	A	A
Railwalk[e]	172.67	*ns*	*ns*	*ns*	*ns*	A	A
Reaction Time							
Simple[b]	0.37	*ns*	*ns*	*ns*	*ns*	A	A
Choice[b]	0.47	*ns*	*ns*	*ns*	*ns*	A	A

Vision							
Acuity							
Far binocular[f]	1.07	*ns*	*ns*	*ns*	*ns*	A	A
Far right eye[f]	1.01	*ns*	*ns*	*ns*	*ns*	A	A
Far left eye[f]	0.96	*ns*	*ns*	*ns*	*ns*	A	A
Near binocular[f]	1.09	*ns*	*ns*	*ns*	*ns*	A	A
Near right eye[f]	1.02	*ns*	*ns*	*ns*	*ns*	A	A
Near left eye[f]	1.02	*ns*	*ns*	*ns*	*ns*	A	A
Phoria							
Far vertical[g]	0.29	*ns*	*ns*	*ns*	*ns*	A	A
Far lateral[g]	0.93	*ns*	*ns*	*ns*	*ns*	A	A
Near vertical[g]	0.39	*ns*	*ns*	*ns*	*ns*	A	A
Near lateral[g]	–3.30	*ns*	*ns*	*ns*	*ns*	A	A
Stereopsis[h]	109.67	*ns*	*ns*	*ns*	*ns*	A	A
Speech Intelligibility[i]	46.80	–7	*ns*	–12	*ns*	A	A

Note. From data reported by Kobrick, Johnson, and McMenemy (1988). $N = 23$. MOPP = Mission-Oriented Protective Posture; BDU = Battle Dress Uniform; *ns* = nonsignificant change from BDU baseline raw score by Student's t ($\alpha = .05$); A = absent—no data collected due to participant withdrawal (voluntary or medical) from test session.

[a]No. of hits. [b]In sec. [c]No. completed. [d]No. of taps. [e]No. of cm walked. [f]Visual angle. [g]Diopters. [h]Sec of arc-degrees. [i]No. correct.

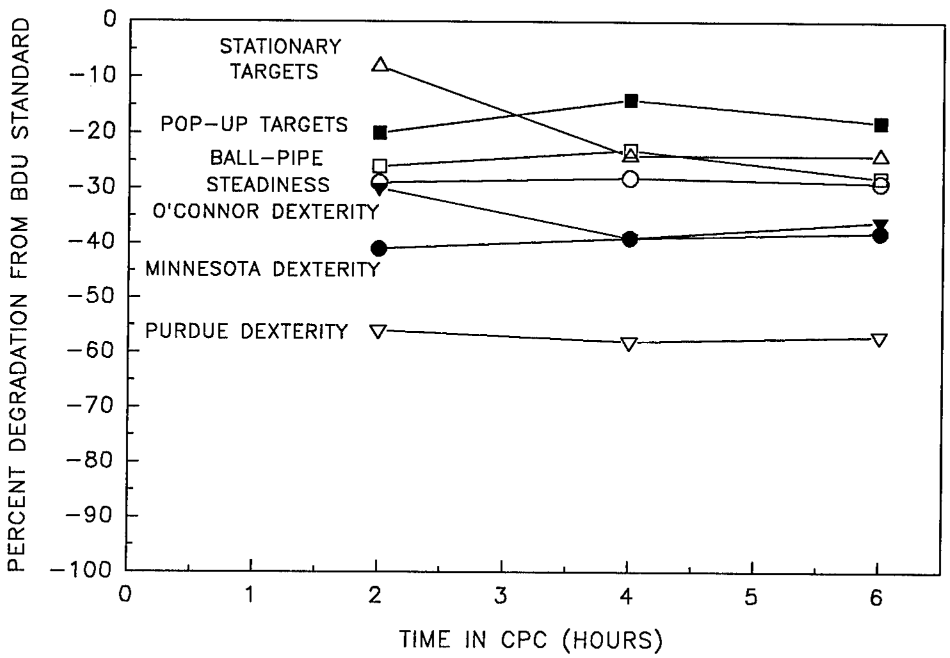

FIGURE 1 Performance in CPC during 6 hr of testing at 55 °F (12.8 °C). CPC = chemical protective clothing; BDU = Battle Dress Uniform.

1985) and monitors its target area for 3 hr. The task is to detect infrequently appearing targets at simulated distances of 250 m and to aim and fire at each detected target. The percent degradation in target detection and firing accuracy continuously for 3 hr of simulated sentry duty (Johnson, 1991) are listed in Table 3.

Rifle firing accuracy while wearing CPC degraded to –19% within the 1st hr of the task, and to –26% by 1.5 hr. Speed of target detection was unaffected during the first 0.5 hr but was degraded –55% at the end of the 1st hr, was degraded –60% by 1.5 hr, and reached a low of –67% at 3.0 hr. The significant impairments in rifle firing accuracy and target detection are shown in Figure 3.

DISCUSSION

Effects of CPC

These findings show clearly and consistently that wearing the MOPP IV protective ensemble resulted in significant impairment of a variety of militarily relevant performance tasks. These clothing-specific effects were evident from the very beginning of performance measurement but did not intensify progressively over the period of heat exposure up to 6 hr.

The largest performance degradations observed were sensorimotor in nature. These degradations, such as arm–hand steadiness, are meaningfully related to the corresponding degradations in M16 rifle marksmanship performance because accurate rifle marksmanship requires accurate motor response, including arm–hand steadiness, to the sensing of rapidly appearing targets.

Peripheral vision was impaired by wearing the M17A1 gas mask most probably because it occluded the entire visual field except for the eyepieces, which are not much larger than the lenses of typical eyeglasses. Other measures of visual performance (acuity, phoria, and stereopsis) were unaffected by wearing CPC because they do not involve peripheral vision, and the clarity of central vision was sufficient through the eyepieces to perform those tasks satisfactorily. However, fogging of the eyepieces was commonly reported as a recurring problem during field operations and could possibly create further visual impairments beyond those observed in this study.

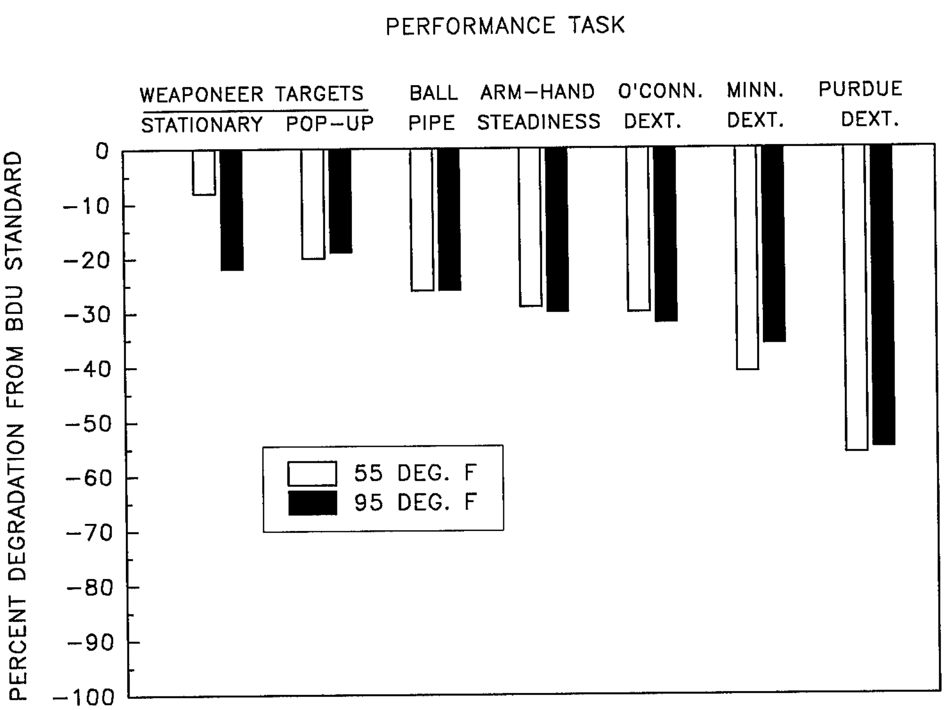

FIGURE 2 Performance in CPC during the first 2 hr of testing at 55 °F (12.8 °C) and at 95 °F (35 °C). CPC = chemical protective clothing; BDU = Battle Dress Uniform.

TABLE 2
Percent Degradation of Performance in MOPP IV Compared to Standard Performance in BDU

	Baseline Mean	Percent Degradation					
	70 °F (21.1 °C)	*55 °F (12.8°C)*			*95 °F (35 °C)*		
Performance Task	*<2 Hr in BDU*	*<2 Hr*	*2.0–3.9 Hr*	*4.0–6.0 Hr*	*<2 Hr*	*2.0–3.9 Hr*	*4.0–6.0 Hr*
Marksmanship (Weaponeer)[a]							
Shot group tightness[b]	1.00	*ns*[c]					
Accuracy[d]	27.40	–19[c]					
Manual Dexterity[e]							
Purdue Pegboard[f]	61.00	–183[g]					
O'Connor Finger Dexterity[f]	80.00	–38[g]					
Visual Field Perimetry[h]							
Target detection latency[f]	1.73		–25[i]			–28[i]	
Speech Intelligibility[j,k]	99.00	*ns*	*ns*	*ns*	*ns*	*ns*	16

Note. MOPP = Mission-Oriented Protective Posture; BDU = Battle Dress Uniform; *ns* = nonsignificant change from BDU baseline raw score by Student's t ($\alpha = .05$).

[a]From data reported by Johnson, McMenemy, and Dauphinee (1990), which involved no heat exposure. $N = 30$. [b]No. of attempts. [c]No data were collected beyond 60 min. [d]No. of targets hit. [e]From data reported by Johnson and Sleeper (1986), which involved no heat exposure. $N = 22$. [f]In sec. [g]No data were collected beyond 30 min. [h]From data reported by Kobrick and Sleeper (1986). $N = 16$. [i]These percent changes are averages over 8 hr. [j]From data reported by Johnson and Sleeper (1985), in which heat exposure was 91 °F (32.8 °C), 61% relative humidity. $N = 23$. [k]Percent correct.

TABLE 3
Percent Degradation of Sentry Duty Performance in MOPP IV Compared to Standard Performance in BDU

	Baseline Mean[a]	*Percent Degradation*					
Performance Task	*0.5 Hr*	*0.5 Hr*	*1.0 Hr*	*1.5 Hr*	*2.0 Hr*	*2.5 Hr*	*3.0 Hr*
Sentry Duty (Weaponeer)							
Target detection latency[b]	656	*ns*	–55	–60	–45	–43	–67
Accuracy[c]	10.30	–13	–19	–26	–25	–15	–22

Note. From data reported by Johnson (1991). $N = 12$. MOPP = Mission-Oriented Protective Posture; BDU = Battle Dress Uniform; *ns* = nonsignificant change from BDU baseline raw score by Student's t ($\alpha = .05$).
[a]BDU at 70 °F (21.1 °C). [b]In msec. [c]No. of targets hit.

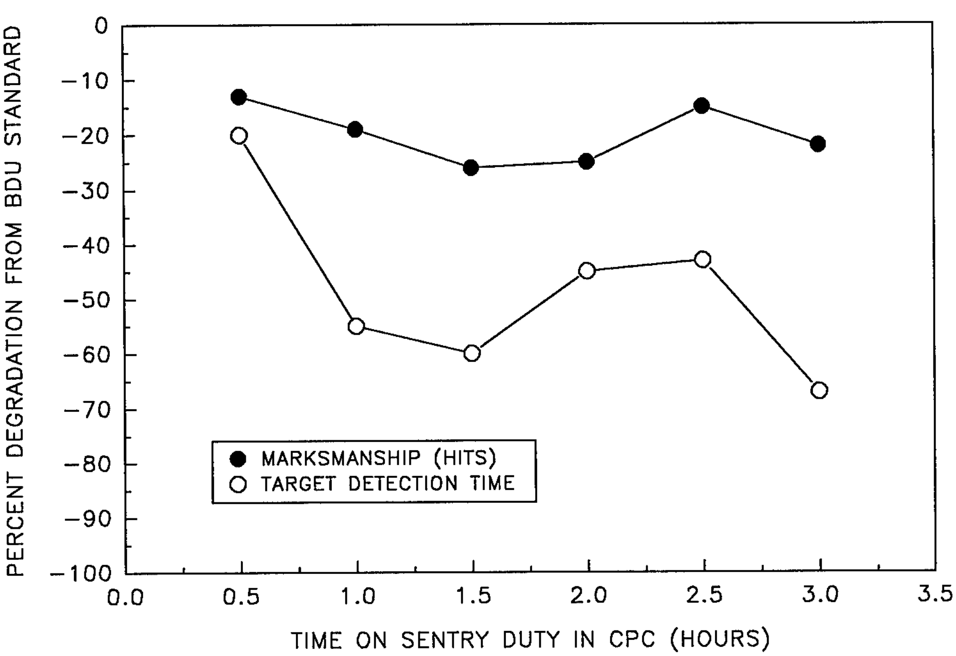

FIGURE 3 Sentry duty performance (rifle marksmanship and target detection) in CPC under thermoneutral conditions. CPC = chemical protective clothing; BDU = Battle Dress Uniform.

Speech intelligibility was impaired because the rubber hood integral to the gas mask covered the ears and attenuated volume and frequency levels of speech, a finding verified by audiometric data collected in the same study (Johnson & Sleeper, 1985).

Effects of CPC and Ambient Heat

Wearing CPC during exposure to ambient heat at 95 °F (35 °C), 60% RH produces heat stress and reduces endurance time to 2 hr or less. During those first 2 hr of heat exposure, however, soldier performance in MOPP IV was comparable to that under thermoneutral conditions in MOPP IV. Beyond 2 hr, the soldiers in MOPP IV withdrew from the test chamber due to heat stress and ceased to perform altogether. This is an important finding for unit commanders and military planners because of the crucial nature of MOPP IV protection and how it affects military task performance.

Effects of CPC on Vigilance and Simulated Sentry Duty

Studies of simulated sentry duty show that CPC shifts the entire vigilance decrement curve toward poorer vigilance and degrades rifle marksmanship throughout 3 hr of simulated sentry duty. Although speed of target detection in both MOPP IV and BDU was impaired as early as 30 to 60 min into task performance, target detection speed in MOPP IV was degraded 55% to 67% beyond that in BDU throughout the full 3 hr period. Rifle firing accuracy while wearing CPC was immediately and continually impaired compared to BDU performance, which we attribute to the difficulty in rapidly aligning the rifle sights with the target while looking through the eyepieces of the chemical protective mask.

SUMMARY AND CONCLUSIONS

This article reviews U.S. Army Research Institute of Environmental Medicine laboratory studies on effects of wearing CPC on rifle marksmanship and on sensory and psychomotor tasks. Soldier performance in the BDU under thermoneutral conditions was the standard for comparison used to calculate a common measure of performance throughout (percent change in performance compared to the standard). Soldier performance while wearing CPC versus BDU was evaluated using this percent change in performance as a function of test duration and the presence or absence of ambient heat.

We have reached several conclusions:

1. Substantial impairments in soldier performance are caused by wearing CPC, but these impairments are relatively unaffected by the length of time CPC is worn under thermoneutral ambient temperature conditions.
2. Although ambient heat exposure (95 °F [35 °C], 60% RH) while wearing CPC produces heat stress and reduces endurance time to 2 hr or less, the addition of ambient heat does not markedly degrade sensory and psychomotor performance during the first 2 hr of wear beyond those levels measured under thermoneutral conditions.
3. During simulated sentry duty, length of time in CPC degrades speed of target detection beyond that attributed solely to time on the task, and rifle firing accuracy is degraded earlier than it would with the BDU.
4. Application of the percent-change index, reflecting percent degradation compared to the BDU standard, is a useful technique for interpreting results across several studies involving a number of different dependent variables.

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Donna J. Merullo (née McMenemy) assisted in the recalculation of the original data (Kobrick, Johnson, & McMenemy, 1988) presented in Table 1. The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

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Effects of Chemical Protective Clothing and Heat Stress on Army Helicopter Pilot Performance

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The U.S. Army Aeromedical Research Laboratory investigated performance of helicopter pilots flying in both temperate and hot weather, with and without various types of chemical protective clothing (CPC) and pilot cooling systems. These studies were conducted in the field and in laboratory environments and evaluated aviator performance under conditions that increase thermal loading to explore heat stress in aviation operations. The investigations defined expected flying limits and examined flight performance under these conditions. The results of early studies prompted evaluations of personal cooling devices and their functional utility for aviators. These investigations provided critical information to the operational community about the effects of CPC and heat stress on aviators operating in varied environments, especially hot desert or tropical climates.

The effects of heat stress on Army helicopter pilot performance have been under investigation at the U.S. Army Aeromedical Research Laboratory (USAARL) for several years. The lack of air conditioning in the majority of Army rotary-wing aircraft has raised serious concerns about the impact of heat stress on pilots required to fly in hot environments. This is especially a problem when the flight missions must be completed while pilots are wearing chemical protective clothing (CPC), which is sealed against outside air and prevents normal body cooling from sweat evaporation. However, heat stress is a concern for Army aviators regardless of whether or not they are wearing chemical protective ensembles.

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Thornton and Guardiani (1992) documented the fact that helicopter cockpit temperatures are often significantly higher than ambient air temperatures, especially in closed cockpits. They reported that the Wet Bulb Globe Temperature (WBGT) in a closed helicopter cockpit during a low hover was an average of 7.0 °F (3.9 °C) higher than it was in the open air on the ground. Similarly, during low-level flight with the cockpit closed, WBGT was 4.9 °F (2.7 °C) higher than it was on the ground. Thus, even under normal circumstances, helicopter pilots are likely to encounter heat stress when operating in warm environments.

IN-FLIGHT STUDIES

CPC

Hamilton, Folds, and Simmons (1982) were among the first to evaluate the effects of heat stress on helicopter pilots flying in warm environments while wearing CPC ensembles. This study was conducted in a UH-1 aircraft, the medical evacuation helicopter in use at the time (see Figure 1). This aircraft was instrumented with a computerized flight performance monitoring system to objectively measure pilot performance. Participants were tested in their standard flight suit, a U.S. Army Aircrew Chemical Defense Ensemble, and a United Kingdom Aircrew Chemical Defense Ensemble. Each participant was tested for 3 days, each day wearing a different suit. A rest day was included between each test day. Although the results indicated that participants experienced heat stress only in the U.S. ensemble, no clear decrements in pilot capabilities were found with either the U.S. ensemble or the United Kingdom ensemble, despite significant physiological evidence of heat stress with the U.S. ensemble. Because some of the research participants were withdrawn early for exceeding medical safety limits while wearing the U.S. ensemble, it was quite clear that aviators would likely suffer dangerous levels of heat stress if required to don CPC while flying in hot, humid environments.

Microclimate Cooling Devices

A similar study by Mitchell et al. (1986) investigated the effects of heat stress on helicopter pilots flying in warm environments while wearing CPC ensembles with the addition of microclimate cooling vests. Three different vests were tested: an airflow vest with a refrigerant cooling unit, a liquid-medium vest with a refrigerant unit, and an airflow vest with a thermoelectric heat pump. Participants flew one standard flight profile each day over a 6-day period in each condition either with or without a cooling vest. The results of this study indicated that the cooling vests were successful in preventing significant elevations in core body temperature, but no vest was shown to be more effective than another. However, the cooling vests did affect mood as well as psychological variables that were sensitive to heat stress.

FIGURE 1 The UH-1 helicopter.

At the time, it was not possible to clearly delineate tolerance times for aviators operating under different temperature extremes in various clothing ensembles because there was no capacity to systematically control the temperature and humidity of the cockpit environment. Despite this fact, aviators and commanders in operational environments continued to seek reliable heat-stress information, and the advent of new aircraft (the UH-60 replaced the UH-1) and different types of aviator uniforms (i.e., new chemical defense ensembles) made further research necessary. Also, although all of the Army's utility helicopters, heavy lift helicopters, and many of the attack helicopters still have no air conditioning, new personal cooling devices have been developed, which require testing in realistic aviation settings prior to acceptance for general use.

SIMULATOR STUDIES

The introduction of the USAARL UH-60 research flight simulator made accurate testing possible because it includes a specially designed environment control system in a fully instrumented, 6-degree-of-freedom motion-base, full-visual, helicopter simulator (see Figure 2). The control system can regulate cockpit temperatures from 68 °F (20 °C) to 105 °F (41 °C) and can regulate the relative humidity (RH) from 50% to 90%. Recently, this simulator has permitted well-controlled investigations of the effects of heat stress on aviator performance and assessments of microclimate cooling systems proposed to prevent or reduce the effects of heat stress.

CPC

The first study in the UH-60 flight simulator was conducted to determine the effects of heat stress in a controlled temperature environment on the physiology and performance of pilots wearing a developmental aviator chemical defense clothing ensemble (Thornton & Caldwell, 1992, 1993; Thornton, Caldwell, Clark, Guardiani, & Rosario, 1992). Sixteen male Army aviators participated in an investigation of two environmental conditions: The cool condition was 70 °F (21 °C), 50% RH; the hot condition was 95 °F (35 °C), 50% RH. On separate days during the study

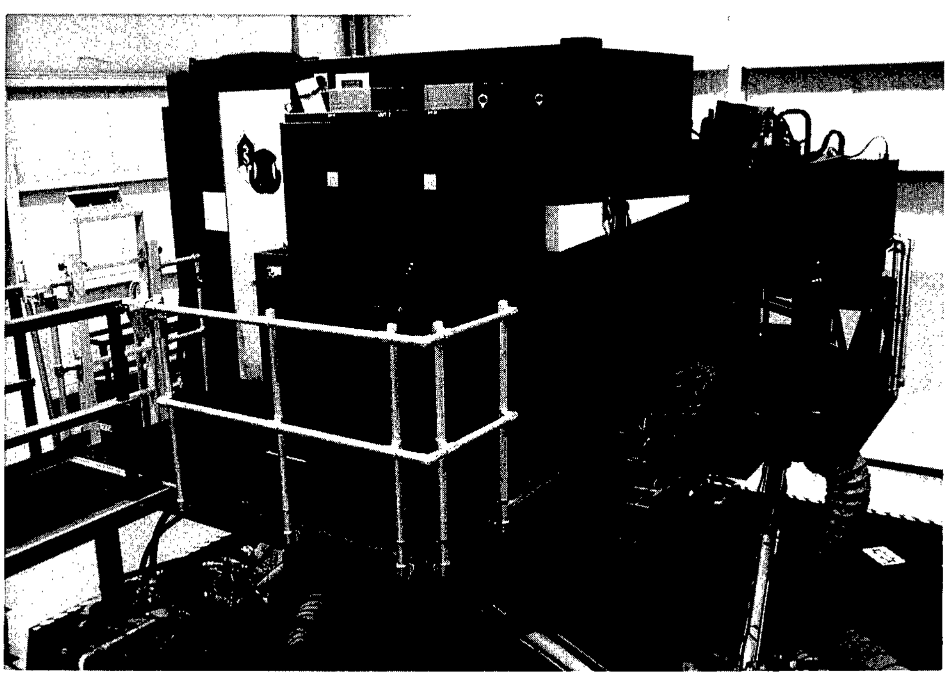

FIGURE 2 The U.S. Army Aeromedical Research Laboratory UH-60 research flight simulator.

FIGURE 3 The U.S. Army Aircrew Uniform Integrated Battlefield and M43 Aircrew Member Protective Mask.

period, each aviator wore two clothing ensembles: nuclear/biological/chemical (NBC) individual protective equipment (IPE) or standard U.S. Army Nomex flight clothing. Figure 3 shows the NBC IPE consisting of the U.S. Army Aircrew Uniform Integrated Battlefield (AUIB) currently under development and M43 Aircrew Member Protective Mask (AMPM). The standard Nomex single-piece flight suit was worn on days when the AUIB was not required. U.S. Army standard issue aviator body armor and a survival vest were worn over both ensembles.

Core body temperature, skin temperature, and heart rate were monitored throughout each flight, and a fatigue checklist was administered.

During the first week, pilots were trained on the flight profile. Participants wore their standard Nomex flight suit the first 3 days and the chemical protective AUIB the last 2 days. The cockpit temperature was set at 70 °F (21 °C) during each of

TABLE 1
Experimental Design For Study of Army Aviators in Two Environmental Conditions

Day	*Clothing*	*Time*
Week 1[a]		
Monday		
a.m.	Flight suit	2 hr
p.m.	Flight suit	2 hr
Tuesday		
a.m.	Flight suit	2 hr
p.m.	Flight suit	2 hr
Wednesday		
a.m.	Flight suit	2 hr
p.m.	AUIB	2 hr
Thursday	AUIB	4 hr
Friday	AUIB	6 hr
Week 2[b]		
Monday[c]	Flight suit, T1	
Tuesday	Flight suit, T2	
Wednesday	AUIB, T1	
Thursday	AUIB, T2	
Friday	Flight suit, T1	

Note. Data are from Thornton, Caldwell, Clark, Guardiani, and Rosario (1992). AUIB = Aircrew Uniform Integrated Battlefield; T1 = cool temperature (70 °F [21 °C]); T2 = hot temperature (95 °F [31 °C]).
[a]Week 1 was spent in training. [b]Week 2 was counterbalanced. [c]At baseline.

three 110-min flights per day. (A 10-min "refueling" stop was made between each flight.) Each participant on the two-person team spent equal time as pilot and copilot and wore the same type uniform as his teammate during each flight. During the test week, pilot and copilot flew 2 days in the standard flight suit and flew 2 days in the AUIB. With each type of clothing, 1 day was spent in the cool condition, and 1 day was spent in the hot condition (Table 1).

Pilots performed nine separate helicopter maneuvers, each of which was scored on up to five different parameters converted to root mean square errors prior to analysis.

When pilots wore the AUIB in the hot (95 °F [35 °C]) environment, their survival times were reduced considerably; only 9 of the 16 participants completed the full 6 hr of flights (Table 2). Aviators who did not complete the flights were withdrawn due to exceeding established physiological safety limits, or they voluntarily withdrew themselves because of the discomfort associated with flying under these conditions. All 16 aviators completed the flights in the other less stressful conditions.

In addition, the performance of pilots who wore the AUIB in the hot environment degraded significantly. Of the nine separate maneuvers flown, there was at least one significant increase in pilot control error for each maneuver under the AUIB hot condition. In addition, most aviators were dehydrated during the AUIB hot condition, partially because they had trouble using the drinking tube in the M43 mask, which preventing them from drinking enough water to maintain hydration.

The findings from the flight and physiological data suggest that heat stress combined with the increased task loading associated with actual in-flight operations increases pilot errors. This is particularly noteworthy because the "hot" environmental condition used in this study was 95 °F (35 °C)—a temperature much less than the over-100 °F (38 °C) temperatures encountered in the Middle East during Operation Desert Storm. In fact, a pilot study conducted before this investigation revealed that, when cockpit temperatures reached approximately 105 °F (41 °C), both pilots were withdrawn before completion of even one flight (at 33 min and 78 min, respectively) due to excessive core body temperature. Thus, the results reported here are not representative of a worst-case scenario and probably underestimate the adverse environmental conditions of many militarily significant theaters of combat.

TABLE 2
Tolerance Times of Participants in the Hot (95 °F [35 °C]) Condition

Participant Number	*Tolerance Time (in Min)*
03	360
04	276
05	180
06	60
07	360
09	180
10	360
11	320
12	240
13	360
14	360
15	360
16	360
17	360
18	270
19	360

Note. Data are from Thornton, Caldwell, Clark, Guardiani, and Rosario (1992).

The most recent study (Reardon, Smythe, Omer, Helms, Hager, et al., 1997; Reardon, Smythe, Omer, Helms, Estrada, et al., 1997) conducted with the current CPC in use by the U.S. Army evaluated 14 aviators in the UH-60 simulator while they wore either the standard aviator uniform or the full, Mission-Oriented Protective Posture Level IV protective suit (including aviation life-support equipment vest and laminated ballistic plate) while flying in either a 70 °F (21 °C) or a 100 °F (38 °C) cockpit with 50% RH. The simulated flights consisted of a 2-hr flight, a 10-min refuel, and another 2-hr flight. Analyses of flight performance, physiological parameters, and mood indicated that the combination of a hot cockpit with full CPC led to decreased performance, increased physiological parameters such as heart rate, core body temperature, and dehydration, and increased symptoms such as heat stress, nausea, dizziness, headache, and thirst. This study supported the previous studies that indicated that heat combined with CPC cannot be well tolerated by aviators.

Microclimate Cooling Systems

Having determined the deleterious impact of heat stress on pilot tolerance, another study assessed the feasibility of reducing heat-related problems by using personal microclimate cooling systems (Caldwell, Thornton, Pearson, & Bradley, 1993; Thornton, Caldwell, Guardiani, & Pearson, 1992). Nineteen aviators wore the NBC AUIB in two ambient temperature conditions on separate test days while wearing either an air-based or liquid-based microclimate cooling system. The air-cooled microclimate cooling vest was worn over a T-shirt, immediately under the AUIB. A vent on the unit also allowed a fan to circulate ambient air.

The liquid-cooled microclimate cooling vest was similar except that cool water instead of air was circulated through the vest. The cooling unit was used with the Exotemp vest, a long-sleeved turtleneck shirt worn in place of an undershirt, and a hood that keeps the head cool.

As in the previous heat-stress study, 19 aviators were required to fly the simulator for 6 hr (three 110-min flights per day, with a 10-min refuel break between each flight). Two heat conditions were used: (a) the 95 °F (35 °C), 50% RH used in the earlier investigation; and (b) the 105 °F (41 °C), 50% RH that had earlier been abandoned due to extreme reductions in tolerance times.

For the first 2 days, pilots trained on the flight profile in the standard Nomex flight suit and then in the AUIB with no cooling and flew both days in a cool cockpit (70 °F [21 °C]). Testing began on the third day with one condition flown for 6 hr each day: The conditions were as follows:

1. 95 °F (35 °C), no cooling;
2. 95 °F (35 °C), air-cooled vest;

3. 95 °F (35 °C), liquid-cooled vest;
4. 105 °F (41 °C), no cooling;
5. 105 °F (41 °C), air-cooled vest;
6. 105 °F (41 °C), "vent-only" (i.e., air-cooled vest with only the blower on); and
7. 105 °F (41 °C), liquid-cooled vest.

Conditions were counterbalanced, with the constraint that the three most stressful conditions (Conditions 1, 4, and 6) were not scheduled consecutively in order to minimize cumulative effects from heat stress or dehydration.

In addition to physiological and flight performance data gathered during flight segments, 8 of the 19 participants also slept in the laboratory, and their sleep was recorded in order to investigate the effects of the environmental conditions during the day on sleep parameters at night.

Results showed that physiological status did not degrade significantly when the cooling systems were used, with lower core temperatures resulting from the liquid-cooled vest than from the air-cooled vest. Also, heart rate was slower during the cooled versus the uncooled conditions, with liquid cooling causing a lower rate at the 95 °F (35 °C) condition and air cooling associated with the lower heart rate at the 105 °F (41 °C) condition. The rate of dehydration with either cooling system was reduced to less than half the rate measured when no cooling was used.

In terms of the effects of heat versus microclimate cooling on postflight nighttime sleep measures, it was observed that REM sleep differed among the conditions. This effect appeared to be the result of an interaction between core temperature increases (≥1.8 °F [0.9 °C]) and uninterrupted time in the simulator (at least 5 hr). Both of these circumstances occurred in the 105 °F (41 °C) liquid-cooled and air-cooled conditions and resulted in decreased REM sleep in comparison to conditions during which core temperature was not elevated for a long period of time. In the uncooled condition, however, participants were not heat stressed long enough to affect REM sleep. Thus, it appeared there was a heat-related reduction in sleep quality if the duration of heat stress was at least 5 hr (Figures 4 and 5).

In terms of actual flight performance, the effects of heat and microclimate cooling were examined through two means: (a) individual pilot survival, or tolerance times, and (b) objective measures of flight control accuracy. One of the best indicators of how well an aviator can perform in AUIB and microclimate cooling is tolerance time, or the amount of time the aviator remains in the cockpit before personally choosing to terminate the flight or before withdrawing for exceeding the physiological safety criteria. Results showed that tolerance time was significantly shorter in the 105 °F (41 °C) no-cooling condition than in all the other conditions (Table 3).

The effects on flight performance with respect to simulator flight control accuracy (i.e., the ability of pilots to maintain precise heading, altitude, airspeed, etc.) indicated an overall cooling-related improvement in only a small portion of

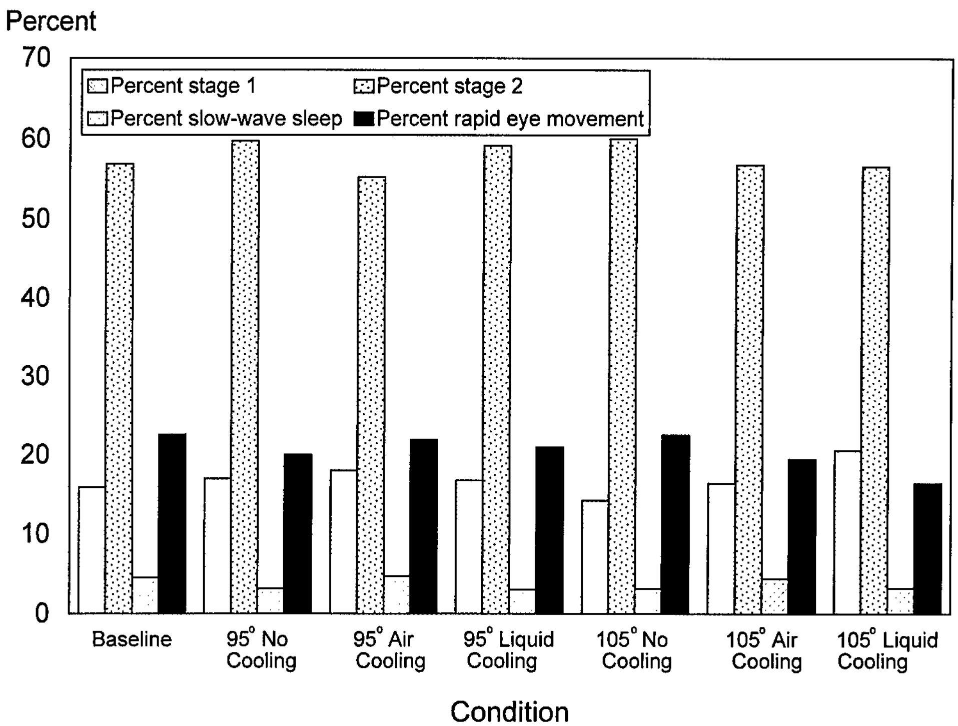

FIGURE 4 Percentage of time in each sleep stage by condition (from Thornton, Caldwell, Guardiani, & Pearson, 1992).

the maneuvers for both cooling systems in comparison to no cooling. Comparing cooling with no cooling under 105 °F (41 °C) was difficult because the pilots did not continue with the test long enough without cooling to make valid statistical comparisons—a fact that is militarily significant in and of itself. When the vent-only condition (blower with no cooling) was compared to the air-cooled condition at 105 °F (41 °C), there was a significant improvement in performance for 11 of the 55 maneuvers under the air-cooled condition. Thus, tolerance time and flight performance improved with microclimate cooling, with the air-cooled systems slightly better than the liquid-cooled system.

Operational Heat Stress Studies

During Operations Desert Shield and Desert Storm, aviation commanders expressed considerable concern over maintaining aviation support in the desert environment under threat of chemical attack. Because of the need for a quick

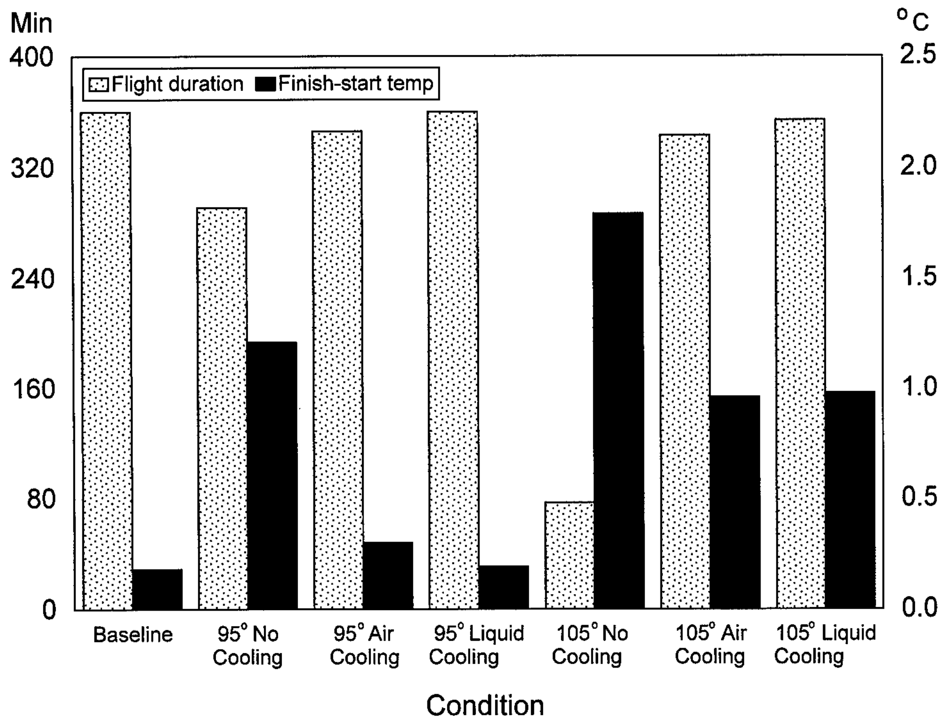

FIGURE 5 Flight duration and temperature rise by condition (from Thornton, Caldwell, Guardiani, & Pearson, 1992).

response, a study involving only two aviators evaluated five microclimate cooling systems to determine the best system to be sent to the aviators flying in Saudi Arabia (Thornton, 1991). Participants wearing CPC flew a total of 5 flight profiles of approximately 2 hr each with the cockpit temperature set at 95 °F (35 °C). Using questionnaires, participants evaluated five cooling systems, one system per flight profile. The participants' recommendations for a system to be used by their fellow aviators in Saudi Arabia were given to the U.S. Army Natick Research, Development and Engineering Center to include with results from other tests conducted with these cooling systems. As a result, this brief evaluation of cooling systems also answered an immediate operational need.

A second study was also requested during Operation Desert Shield to examine the combined effects of heat stress and pyridostigmine, a chemical defense prophylactic pretreatment drug (Thornton, 1992). Again, due to the need for an immediate answer, only 2 participants were evaluated, each of whom flew the UH-60 simulator up to 6 hr on 2 consecutive days while wearing CPC. The cockpit temperature was maintained at 95 °F (35 °C). Each participant received one dose of 30-mg oral

TABLE 3
Tolerance Times (in Min) Per Condition

	Cooling Condition						
	95 °F (35 °C)			*105 °F (41 °C)*			
Participant Number	*None*	*Air*	*Liquid*	*None*	*Vent*	*Air*	*Liquid*
03	360	360	360	40[a]	113[a]	360	360
04	225[a]	360	360	55[a]	66[a]	360	360
05	118	249	360	74[a]	89	225	312
06	330	360	360	74[a]	201[a]	242[a]	360
07	220	360	360	82[a]	180	360	360
09	149	360	360	50	150[a]	315	271
10	295[a]	360	360	130[a]	202	322[a]	197[a]
11	260	360	360	142	360	322[a]	360
12	360	360	330	60[a]	115	360	290
13	360	360	360	105[a]	115	360	360
14	360	360	360	82[a]		360	113
15	330	360	360	69[a]		360	258
16	257	360	360	58	85	360	155
17	360	360	360	90[a]	125[a]	360	360
18[b]	360	360	360	65[a]	259	300[c]	205
19[b]	310	360	360	65[a]	288	300[c]	360
M	285	353	358	79	150	333	294

Note. Data are from Thornton, Caldwell, Guardiani, and Pearson (1992). A blank space indicates the condition was not recorded.
[a]Reached physiological criteria. [b]Data not included in mean. [c]Run halted due to cooler failure.

pyridostigmine 1 hr before the flight on one day and a placebo tablet on the other day in a double blind, cross-over design. Each day, 1 participant received the active drug and 1 received a placebo, and each participant's physiological measures were investigated under each condition. Only 1 participant's rectal and skin temperature were twice as high with pyridostigmine than with placebo, but both participants showed an increase in sweat rate after the drug. Because the number of participants for this study was so small, however, no definite conclusions could be reached concerning pyridostigmine.

CONCLUSIONS

The research performed by USAARL on the effects of CPC and heat stress on helicopter pilot performance has contributed valuable information about aviators operating in desert environment, tropical environments, or both. The results of these studies indicate that pilots who fly in a hot environment while wearing CPC without microclimate cooling will suffer from significant heat stress, and chemical defense medicines could exacerbate this problem. Thus, helicopter missions should be shortened under these circumstances, or aviator safety will be compromised along with performance and psychological well-being. The tests further indicate that heat stress can be reduced significantly if cooling equipment is available, preferably air-cooled rather than liquid-cooled systems.

One of the most important findings was that most aviators could not safely fly a single standard mission (1 fuel load or 2 hr) with NBC IPE in 105 °F (41 °C) heat without some type of cockpit or individual cooling equipment. This is particularly noteworthy considering the military conflicts in Southeast Asia, Saudi Arabia, Haiti, and Somalia, in which the environmental temperatures were extreme and, in at least one case, the threat of chemical warfare was imminent.

Because heat stress studies conducted with *controlled* environmental conditions in a helicopter simulator indicated that heat negatively affects both flight performance and the physiological status of helicopter pilots, it is concluded that microclimate cooling devices are necessary under extreme, but *realistic,* environmental circumstances. Microclimate cooling prevents decrements in performance and increases tolerance time by reducing the physiological effects of heat such as increased core body temperature, heart rate, and dehydration.

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Effects of Chemical Protective Clothing, Exercise, and Diphenhydramine on Cognitive Performance During Sleep Deprivation

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The cognitive performance effects of some stressors experienced in military training and combat were determined in a field experiment. The effects of wearing chemical protective clothing (CPC) at Mission-Oriented Protective Posture Level IV, walking 18 to 24 miles (29–39 km) while carrying a heavy backpack, and taking 50-mg oral doses every 6 hr of diphenhydramine (an antihistamine) were investigated on 72 Marines during a 36-hr sleep deprivation double-blind, placebo-controlled experiment. We administered tests that measured reaction time, spatial ability, memory, and logical reasoning. The results suggest that wearing CPC for an 11-hr period or prolonged engagement in moderate exercise produces general cognitive impairment in sleep-deprived participants. However, after repeated dosing, taking diphenhydramine has little cognitive effect. These results suggest that, if a job is near the limit of a person's cognitive abilities, performance may suffer if the person is sleep deprived and required to wear CPC or engage in prolonged, moderate exercise.

Military personnel are faced with stressors that may compromise their ability to perform their mission. Apart from the emotional intensity of combat, other stressors may adversely affect fighting ability. Combat often requires physical exertion and sometimes requires wearing chemical protective clothing (CPC). Furthermore,

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soldiers may take medication, such as a chemical warfare prophylactic or antidote, or over-the-counter drugs. Additional stress may result from insufficient sleep and subsequent fatigue. The effects of these stressors on soldiers may be cumulative and synergistic. The effects of three specific stressors—wearing CPC, exercising, and taking diphenhydramine—are reviewed.

Military CPC, designed to protect the wearer from agents used in biological or chemical warfare, is impermeable and allows minimal evaporation of the wearer's perspiration. Depending on the duration worn, activity level, and environmental circumstances, perspiration may pool in face mask, boots, and gloves. CPC ensembles are also cumbersome, requiring soldiers to expend greater energy to move. Even with soldiers experienced in wearing CPC, this clothing may produce panic, confusion, dyspnea, and fear in 20% of them; some of these reactions may occur in the first 10 min of an exercise or immediately after putting on the mask (Brooks, Xenakis, Ebner, & Balson, 1983). Carter and Cammermeyer (1985) found that the most frequent complaints of those wearing CPC were rapid breathing, shortness of breath, and loss of peripheral vision, which were experienced by 49% of the participants. Simply being confined in the suit may produce panic in individuals susceptible to claustrophobia. Apart from the problem of encapsulation, wearing the gas mask respirator increases breathing effort and can lead to physiological and psychological problems for some people. Gas masks and other filter respirators alter pulmonary function (Kelly et al., 1987; Raven, Dodson, & Davis, 1979), decrease endurance (Craig, Blevins, & Cummings, 1970; Stemler & Craig, 1977), and produce adverse psychological consequences, such as panic (Brooks et al., 1983; Carter & Cammermeyer, 1985; Morgan, 1983; Morgan & Raven, 1985).

Previous research on the effects of wearing a protective mask, without other protective clothing, has shown cognitive decrements. Spioch, Kobza, and Rump (1962) showed an increase in reaction time on the Bourdan test, which is a letter, number, and word cancellation test. On comparable participants, wearing the M17A2 facial mask resulted in a decrement in Simple Reaction Time performance and a decrement in the number of responses in a tapping test but resulted in no difference in Wilkinson's Four-Choice reaction time test or Baddeley's Logical Reasoning test (Kelly, Ryman, et al., 1988). This suggests that the mask may be responsible for some of the decrements in cognitive performance when participants wear CPC. These decrements could result from the restricted visual field and from the psychological and physiological effects of wearing a respirator.

Previous research on the effects of wearing CPC on cognitive performance has produced mixed results. The majority of the research found evidence of a cognitive performance decrement (Englund et al., 1987; Englund, Sucec, Yeager, Ryman, & Sinclair, 1988; Kelly, Englund, Ryman, Yeager, & Sucec, 1988; Kobrick & Sleeper, 1986; Rauch, Witt, Banderet, Tauson, & Golden, 1986), which has been attributed to the physical effects of wearing CPC—chiefly the limited vision produced by wearing the mask and the clumsiness produced by wearing the gloves. However, some researchers have not found any cognitive performance decrement (Arad et al., 1992; Hamilton, Simmons, & Kimball, 1983). Fine (1988) put individuals wearing CPC in a hot, humid room and found no cognitive decrement in those who completed the experiment. One report showed that wearing CPC produced an improvement in performance (Hamilton & Zapata, 1983).

The typical finding in the research on the second stressor, exercise, is that it improves cognitive performance (Tomporowski & Ellis, 1986). The few experiments that have addressed strenuous exercise, similar to the level experienced in combat, found facilitation on spatial tests (Lybrand, Andrews, & Ross, 1954), facilitation on vigilance (Gliner, Matsen-Twisdale, Horvath, & Maron, 1979), or slight facilitation on memory, which was not statistically significant (Tomporowski, Ellis, & Stephens, 1987).

The third stressor, diphenhydramine, is an H1-histamine blocker administered for the relief of allergy symptoms. The two most commonly reported side effects are drowsiness (Rickels et al., 1983; Roth, Roehrs, Koshorek, Sicklesteel, & Zorick, 1987) and mental impairment both on cognitive tests (Baugh & Calvert, 1977; Linnoila, 1973; Rice & Snyder, 1993) and on a driving simulator (Gengo, Gabos, & Mechtler, 1990). The effects of diphenhydramine were of interest because of its widespread use and because it was unclear how its side effects of sedation and cognitive impairment would interact with the cognitive changes due to sleep deprivation, exercise, and wearing CPC.

The majority of the research on this drug investigated the effects of a single oral dose of the drug, rather than the effect of repeated doses. Single doses lead to drowsiness and cognitive impairment. About half of patients experienced drowsiness (Gilman, Rall, Nies, & Taylor, 1990), and cognitive impairment was not always found at the standard dosage of 50 mg (Pishkin, Sengel, Lovallo, & Shurley, 1983) or even at twice the standard dosage (Schrot, Thomas, & Van Orden, 1990). When performance decrements are found, they are for some measures on some tests and for a limited duration. At the standard dosage, plasma concentration peaks 2 hr postingestion, stays at that level for another 2 hr (Babe & Serafin, 1996), and has an estimated half-life of 8.5 hr (Benet, Oie, & Schwartz, 1996). Problems with mental impairment typically are maximal 1 to 4 hr postingestion and can last for 5.1 to 6.6 hr (Licko, Thompson, & Barnett, 1986).

Research of the effect of repeated dosing has found that tolerance to the side effects of diphenhydramine develops very quickly (Gilman et al., 1990). The sole study that used repeated dosing found the performance decrement for the 1st day of dosing did not occur in subsequent testing on the 3rd day of dosing (Schweitzer, Muehlbach, & Walsh, 1994). The participants were not tested on the 2nd day of dosing, however, so the rate of achieving tolerance cannot be determined from this study.

The field experiment reported here investigated the cognitive effects of wearing CPC, engaging in prolonged, periodic physical exercise, and taking diphenhydramine in participants who were sleep deprived for 36 hr. The purpose of this study was to determine the level and nature and, when possible, the source of cognitive performance decrements produced by combat-related stressors. This information should facilitate prediction of the operational consequences of these stressors. Thirteen cognitive tests, which assessed reaction time, spatial ability, memory, and reasoning, were administered. The administration of multiple tests within each cognitive ability allowed examination of the pattern of results across tests and provided more generality than would be obtained with the use of fewer tests. This was especially important because the sensitivity of these tests to stressors was unknown (cf. D. Williams, 1995), and some of the tests may be insensitive to stressor-induced cognitive decrement. The use of a variety of tests was especially important in determining the source of the cognitive performance decrement caused by wearing CPC. Depending on the visual angle of information displayed to the participants wearing a gas mask and the response requirements, limitations in vision and dexterity produced by wearing this clothing would be expected to differentially affect performance on cognitive tests having different characteristics. Using several tests allowed estimation of the size of various sources of cognitive performance decrements.

METHOD

Participants

Ninety-six male Marines from the First Marine Division, Camp Pendleton, California, voluntarily participated in the experiment. They ranged in age from 18 to 38 years, and most of the participants had experience wearing CPC. Each participant was studied over a 2-week interval. During the 1st week, they spent 2 days in the laboratory, and during the 2nd week, they spent 4 days in the field. Due to difficulties with the initial data collection, the data from the first 24 participants were not used in the analyses. The results reported here were obtained from the remaining 72 participants.

Materials

Thirteen cognitive tests from the computerized Naval Health Research Center Performance Assessment Battery (PAB) were administered periodically (D. Williams, Englund, Sucec, & Overson, 1995). This PAB is very similar to the widely used Walter Reed PAB (Thorne, Genser, Sing, & Hegge, 1985). The tests chosen from this battery were (a) reaction time tests (Choice Reaction Time, Simple Reaction Time, Tapping, and Wilkinson's Four-Choice), (b) spatial tests (Manikin, Matrix-2, and Time Wall), (c) memory tests (Digit Recall, Single Digit Substitution, and Six-Letter Search), and (d) reasoning tests (Encode/Decode, Logical Reasoning, and Serial Addition/Subtraction). These tests were presented on Zenith model ZVC–1–AA desktop computers, based on the original IBM PC XT architecture.

For most of the tests, the computer presented a stimulus on a computer monitor, and the soldier indicated his response by pressing a key on a computer keyboard. An exception was Tapping, in which a participant alternately pressed two keys with the index finger of his dominant hand. If the participant pressed a nonresponse key when a response was expected or pressed any key when a response was not expected, a warning tone sounded. During practice trials, this tone also sounded after an incorrect response. During both practice and data collection trials, a summary of the participant's performance was presented at the end of each test.

Each participant used his own CPC issued by the Marine Corps, including a prescription lens insert if he required it. Prospective participants who needed these lenses but did not bring them were dropped from the experiment. The CPC was an Overgarment-84 (OG84) suit and either an M17A1 or M17A2 mask. The CPC was worn at the Mission-Oriented Protective Posture Level IV, which provides the maximum protection. The control group for CPC wore the standard camouflage utility uniforms issued by the Marine Corps. Participants wearing CPC and assigned to the exercise condition exchanged the mask issued by the Marine Corps for an M17A2 mask before engaging in exercise, allowing collection of expired air.

Design

The cognitive tests were divided into three batteries. Battery 1 consisted of Single Digit Substitution, Logical Reasoning, Manikin, Six-Letter Search, and Time Wall. Battery 2 consisted of Encode/Decode, Digit Recall, Choice Reaction Time, and Tapping. Battery 3 consisted of Serial Addition/Subtraction, Wilkinson Four-Choice, Matrix-2, and Simple Reaction Time. The tests were administered in the listed order within each battery.

The experiment had both between-subjects and within-subject factors. There were two levels each of exercise (walking with a backpack or sitting), drug (diphenhydramine or placebo), and clothing (CPC or utility work uniform), which were between-subjects factors. As seen in the testing schedule in Table 1, the participants were administered the 13 tests from the three test batteries on four occasions. This within-subject factor was labeled the *block* variable. The design of the entire experiment was a 2 (exercise) × 2 (drug) × 2 (clothing) × 4 (block) factorial. Because of the discomfort of wearing CPC, the participants who wore CPC did so only for the last 11 hr of the experiment, donning the CPC partway through the third testing block. Thus, the experimental design is not a complete factorial. The data reported here are from the final block of trials, making the design a 2 (exercise) × 2 (drug) × 2 (clothing) complete factorial. All data reported are from mildly sleep-deprived participants because the participants had already missed one night of sleep by the beginning of the testing presented here.

TABLE 1
Testing Schedule

Day	*Time*	*Session*	*Battery*	*Block*
Tuesday	0700	1	1	
	0812	2	1	1
	0924	3	2	1
	1036	4	2	1
	1148	5	3	1
	1300	Break		
	1400	6	3	1
	1512	7	1	2
	1624	8	1	2
	1736	9	2	2
	1848	10	2	2
	2000	Break		
	2100	11	3	2
	2212	12	3	2
	2324	13	1	3
Wednesday	0036	14	1	3
	0148	15	2	3
	0300	Long break		
	0700	16	2	3[a]
	0812	17	3	3
	0924	18	3	3
	1036	19	1	4[b]
	1148	20	1	4[b]
	1300	Break		
	1400	21	2	4[b]
	1512	22	2	4[b]
	1624	23	3	4[b]
	1736	24	3	4[b]
	1848	Done		

[a]Chemical protective clothing donned. [b]Data analyzed for effects of chemical protective clothing.

Procedure

Participants were run in groups of 24, and they were randomly assigned to each of the eight conditions. The week prior to the field study, the participants were instructed how to do the cognitive tests and completed each test twice in a laboratory setting. The field study was conducted outdoors and in tents during the summer at Camp Del Mar, Camp Pendleton, California, about a quarter of a mile from the ocean. The temperature during the day was approximately 75 °F (24 °C) and dropped to approximately 65 °F (18 °C) at night.

On the 1st day of the experiment, participants awakened at 0500 hr and began the experiment at 0700 hr. During each 72-min testing interval, the exercisers walked 1 mile (1.61 km) around an outdoor quarter-mile (0.40 km) dirt track, carrying a military backpack that weighed 50% of their body weight. They were paced to maintain a rate of 5.56 km/h for 20 min. During odd-numbered testing intervals, the exercisers completed questionnaires; on even-numbered intervals, they took computerized tests. On odd-numbered testing intervals, the nonexercisers both completed questionnaires and took the computerized tests. During even-numbered intervals, they were assigned reading from military training manuals. The questionnaires and computerized tests were completed and assigned reading was done in tents adjacent to the track. Before taking the computerized tests, physiological measurements such as heart rate, blood pressure, and grip strength, were made; these data are not included in this report.

The participants were given scheduled breaks, including a 1-hr meal break at 1300 hr and 2000 hr. At 0300 hr, the participants were given a 4-hr rest break during which they were monitored to ensure that they did not sleep.

Administration of the diphenhydramine was double blinded and placebo controlled. Participants in the drug condition received 50 mg every 6 hr, the standard adult dosage. The first dose was given before the first testing interval, followed by 6 more doses during the experiment, for a total of 7 doses. The control participants received placebo capsules at each dosing interval.

Participants who wore CPC kept the entire ensemble on except during meal breaks when they removed the hood and the gloves or when they used the restroom. The longest interval they wore the entire clothing ensemble was 5 hr.

Because the participants who wore CPC were not physically able to smoke cigarettes, to ensure comparability of the participants wearing CPC and utility clothing and to simulate the circumstances of military maneuvers, the participants in all conditions were only allowed to smoke during the long break. Few participants smoked during this break, although 36% of the participants reported that they were smokers. Of the participants who completed the experiment, the number of smokers was similar in all conditions.

All 36 participants in the nonexercise group and 26 participants in the exercise group completed the experiment. One participant quit the experiment, and a few became too fatigued to continue. The rest were dropped for medical reasons, mostly due to severe foot blisters. Data for participants who did not complete the experiment were excluded from the analysis.

RESULTS AND DISCUSSION

Dependent Measures and Analyses

A sensitivity analysis was done across four stressors (clothing, drug, exercise, and block), and a single set of four dependent measures was chosen to analyze the effects of the stressors in the entire data set (D. Williams, 1995). The selected measures were maximally sensitive, had minimal overlap with other measures, completely characterized the participants' cognitive performance, and had potential operational relevance. When there was no principled reason to choose one measure over another similar one, the measure used by other researchers was chosen to facilitate comparison of results among studies. This resulted in the selection of two nontraditional measures, Percent Lapses and Correct Per Minute, and two traditional measures, Correct Response Reaction Time and Percent Correct.

Lapses, which are excessively long responses, were first observed in the performance of sleep-deprived participants by Patrick and Gilbert in 1896, and they were confirmed in subsequent research (Bills, 1931, 1958; Bjener, 1949; Warren & Clarke, 1937; H. L. Williams, Lubin, & Goodnow, 1959). The cutoff point used to mark the division between normal responses and excessively long responses was twice the group median. Responses faster than this cutoff were considered normal responses; responses taking longer than this cutoff were considered lapses. Percent Lapses was calculated by dividing the number of lapses by the total number of items presented to which the participant responded. This measure may index the percentage of times the participants lost attentional focus, and it will be referred to as *lapsing*.

Correct Per Minute is the number of correct responses divided by the total response time, and it was computed for each participant. The denominator is the sum of the participant's reaction times, including lapses, and it represents the time he was actually doing the task. It is not the *total* time on task because that measure would include the period of time while the participant waited for the stimulus to be presented. Correct Per Minute is the number of correct reactions per minute of response time and could be called Correct Per Working Minute. This measure combines accuracy and speed data into a single measure that indexes the overall effectiveness of the participant. It has been called "throughput" (Thorne, Genser, Sing, & Hegge, 1983) and an efficiency index (Glenn & Parsons, 1990). Subsequently, it will be referred to as *rate*.

Correct Response Reaction Time is the reaction time for all correct responses, excluding lapses. This is the average amount of time it took participants to answer questions when they performed accurately and responded within a reasonable time and will be referred to as *reaction time*.

Percent Correct is the number correct divided by the number of items presented to which the participants responded, including lapses. Subsequently, it will be referred to as *accuracy*.

These four measures were separately analyzed for each cognitive test using an analysis of variance (Hays, 1973) for a 2 (clothing) × 2 (exercise) × 2 (drug) between-subjects design. The means, standard deviations, and number of participants are tabled for each dependent variable. Test results for the clothing factor are presented in Table 2, activity results are presented in Table 3, and diphenhydramine results are presented in Table 4.

This information was used to calculate effect sizes, also called the *d* statistic (Cohen, 1988), using the following formula: (Experimental Mean – Control Mean)/Pooled Standard Deviation. The *d* statistic is equivalent to the more familiar *z* score. Based on surveys of the social sciences literature, Cohen suggested that *d* statistic effect sizes of 0.2 be considered small, 0.5 be considered medium, and 0.8 be considered large. The *d* statistic effect sizes for each test and dependent measure are presented in Tables 5 through 7. Proponents of meta-analysis challenge the importance of hypothesis testing, and they argue that the *d* statistic reveals a much more consistent picture than that depicted by hypothesis testing (cf. Glass, McGaw, & Smith, 1981; Hunter, Schmidt, & Jackson, 1982; Loftus, 1991, 1993; Schmidt, 1992).

Baseline Data

Participants were randomly assigned to experimental groups with no attempt to match them on any variables. To determine the comparability of the groups, data collected during the training sessions preceding the experimental data collection were analyzed to determine main effects indicating group differences. No differences were found for clothing, three differences were found for activity, and one difference was found for drug.

The activity group differences were in accuracy for Choice Reaction Time, $F(1, 55) = 4.12, p < .047$, in which exercise group members were less accurate, and for Serial Addition/Subtraction, $F(1, 53) = 5.75, p < .020$, in which exercise group members were more accurate. There was also an activity group difference in rate for Single Digit Substitution, $F(1, 55) = 5.07, p < .028$, in which exercise group members worked at a higher rate. For the drug factor, there was a difference in Correct Per Minute for Matrix-2, $F(1, 54) = 6.75, p < .012$, in which drug group participants had a lower rate.

The experimental results for comparisons in which the groups differed at baseline are presented, but they are designated as confounded. These results were not included in averaged estimations of effect size.

Discarding Data

Summary data for each participant were examined to determine whether the participant was attempting to do the task or simply answering as quickly as possible. When the sum of each participant's reaction time for all responses (correct and incorrect, lapse and nonlapse) were less than 20% of the average reaction time, and accuracy was close to chance, all of the participant's data were discarded. Participants were dropped from only 3 of the 13 tasks: 10 from Logical Reasoning, 5 from Six-Letter Search, and 2 from Manikin.

TABLE 2
Cognitive Test Results for Clothing Factor

Test	Correct Response Reaction Time[a]		Percent Lapses		Percent Correct		Correct Per Minute[b]	
	CPC	*Utility*	*CPC*	*Utility*	*CPC*	*Utility*	*CPC*	*Utility*
Reaction time tests								
Choice Reaction Time								
M	1.22	1.10*	5	6	87	96*	40.57	49.11**
SD	0.20	0.17	5	7	20	11	10.80	12.00
n	29	31	29	31	29	31	29	31
Simple Reaction Time[c]								
M	0.44	0.41[d]	29	18*	—	—	91.78	117.71*[d]
SD	0.08	0.07	22	17	—	—	49.10	46.60
n	23	32	23	32	—	—	23	32
Tapping								
M	0.22	0.21[d]	4	3	91	95**[d]	221.95	253.01*[d]
SD	0.03	0.04	4	3	6	6	48.20	63.80
n	29	31	29	31	29	31	29	31
Wilkinson Four-Choice								
M	0.59	0.57[d]	15	4***	70	84**	59.90	87.01***
SD	0.10	0.12	15	5	20	20	20.90	16.80
n	26	33	26	33	26	33	26	33
Spatial tests								
Manikin								
M	1.97	1.73[e]	13	10	90	94[d,e]	25.07	34.21*[d,e]
SD	0.50	0.47	14	14	14	9	9.50	20.10
n	28	31	28	31	28	31	28	31
Matrix-2								
M	1.44	1.16*	25	14**	55	56[d]	15.69	26.54***
SD	0.45	0.40	17	21	11	12	10.90	16.10
n	28	33	28	33	28	33	28	33

Time Wall[f]								
M	0.02	0.01	—	—	—	—	—	—
SD	0.04	0.01	—	—	—	—	—	—
n	28	33	—	—	—	—	—	—
Memory tests								
Digit Recall								
M	3.87	3.80	14	12	39	42[d]	5.32	5.49[d]
SD	1.50	1.30	17	20	22	17	3.10	2.76
n	28	30	29	31	29	31	29	31
Single Digit Substitution								
M	3.14	2.78*	18	12	50	58	7.83	10.54*
SD	0.69	0.51	17	11	20	22	3.40	4.90
n	28	33	28	33	28	33	28	33
Six-Letter Search								
M	4.81	4.18	11	7	76	85*	10.20	16.29*
SD	1.90	2.10	13	11	17	17	5.30	11.70
n	26	30	26	30	26	30	26	30
Reasoning tests								
Serial Addition/Subtraction								
M	1.52	1.34*	20	12**	72	85*	20.67	33.44***
SD	0.28	0.33	14	10	25	21	10.60	14.50
n	28	33	28	33	28	33	28	33
Encode/Decode								
M	26.17	22.87*	4	5	71	83	1.71	2.32*
SD	4.30	5.40	10	11	34	24	0.89	1.09
n	26	31	29	32	29	32	29	32
Logical Reasoning								
M	3.56	3.61[d]	16	15	74	78[d]	11.87	11.54[d]
SD	1.30	0.89	13	19	19	20	6.90	4.37
n	25	29	25	29	25	29	25	29

Note. CPC = chemical protective clothing.
[a]In sec. [b]Correct Per Minute is (No. Correct)/(Total Reaction Time). [c]Simple Reaction Time tabled value is Response Reaction Time. [d]Possible confounding due to the gloves. [e]Possible confounding due to the mask. [f]Time Wall tabled value is the absolute value of (Estimated Arrival Time – Actual Arrival Time)/(Total Fall Time).
*$p < .05$. **$p < .01$. ***$p < .001$.

TABLE 3
Cognitive Test Results for Activity Factor

	Correct Response Reaction Time[a]		Percent Lapses		Percent Correct		Correct Per Minute[b]	
Test	*Exercise*	*Sedentary*	*Exercise*	*Sedentary*	*Exercise*	*Sedentary*	*Exercise*	*Sedentary*
Reaction time tests								
Choice Reaction Time								
M	1.15	1.17	6	5	91	92[c]	43.96	45.76
SD	0.16	0.21	6	6	19	15	12	12.40
n	26	34	26	34	26	34	26	34
Simple Reaction Time[d]								
M	0.44	0.40*	29	18*	—	—	90	118.99
SD	0.07	0.07	17	21	—	—	38	52.80
n	23	32	23	32	—	—	23	32
Tapping								
M	0.21	0.22	5	3**	91	95**	228.60	245.18
SD	0.03	0.04	4	2	8	5	69.40	48.40
n	26	34	26	34	26	34	26	34
Wilkinson Four-Choice								
M	0.58	0.58	9	9	77	78	73.32	76.45
SD	0.10	0.12	9	13	20	22	24.90	21.60
n	26	33	26	33	26	33	26	33
Spatial tests								
Manikin								
M	1.80	1.89	11	12	93	92	27.19	31.98
SD	0.30	0.61	12	16	9	14	9.20	20.30
n	26	33	26	33	26	33	26	33
Matrix-2								
M	1.32	1.27	27	12***	54	57	18.62	23.89
SD	0.43	0.46	24	13	10	13	16.40	13.30
n	27	34	27	34	27	34	27	34

Time Wall[e]								
M	0.02	0.02	—	—	—	—	—	—
SD	0.02	0.03	—	—	—	—	—	—
n	26	35	—	—	—	—	—	—
Memory tests								
Digit Recall								
M	3.65	3.96	19	8*	36	44	4.64	6.00
SD	1.50	1.30	25	9	19	20	2.50	3.10
n	24	34	26	34	26	34	26	34
Single Digit Substitution								
M	2.76	3.09	13	16	53	56	9.37	9.25[c]
SD	0.62	0.58	16	12	19	23	4.10	4.80
n	26	35	26	35	26	35	26	35
Six-Letter Search								
M	4.30	4.61	8	9	78	83	14.20	12.87
SD	2.00	2.10	12	12	17	18	11.30	8.40
n	25	31	25	31	25	31	25	31
Reasoning tests								
Serial Addition/Subtraction								
M	1.38	1.46	17	14	76	81[c]	25.44	29.28
SD	0.26	0.36	14	12	26	22	14.20	14.30
n	27	34	27	34	27	34	27	34
Encode/Decode								
M	24.07	24.58	7	2*	75	80	1.90	2.13
SD	4.60	5.50	13	6	33	27	1.10	0.99
n	23	34	26	35	26	35	26	35
Logical Reasoning								
M	3.63	3.55	21	11*	76	77	9.84	12.97*
SD	0.98	1.20	17	15	17	22	3.90	6.30
n	22	32	22	32	22	32	22	32

[a]In sec. [b]Correct Per Minute is (No. Correct)/(Total Reaction Time). [c]The activity groups differed at baseline on this measure. [d]Simple Reaction Time tabled value is Response Reaction Time. [e]Time Wall tabled value is the absolute value of (Estimated Arrival Time – Actual Arrival Time)/(Total Fall Time).

$*p < .05$. $**p < .01$. $***p < .001$.

TABLE 4
Cognitive Test Results for Drug Factor

	Reaction Time[a]		Percent Lapses		Percent Correct		Correct Per Minute[b]	
Test	*Drug*	*Placebo*	*Drug*	*Placebo*	*Drug*	*Placebo*	*Drug*	*Placebo*
Reaction time tests								
Choice Reaction Time								
M	1.16	1.16	7	4	89	94	44.47	45.52
SD	0.22	0.15	6	5	20	12	11.70	12.80
n	31	29	31	29	31	29	31	29
Simple Reaction Time[c]								
M	0.42	0.42	24	21	—	—	106.21	107.50
SD	0.09	0.07	21	18	—	—	55.30	42.50
n	28	27	28	27	—	—	28	27
Tapping								
M	0.22	0.21	4	3	92	94	227.64	249.06
SD	0.03	0.04	3	3	7	5	54.90	61.10
n	31	29	31	29	31	29	31	29
Wilkinson Four-Choice								
M	0.57	0.58	10	7	78	78	73.73	76.56
SD	0.10	0.10	14	9	23	19	23.70	22.50
n	31	28	31	28	31	28	31	28
Spatial tests								
Matrix-2								
M	1.31	1.26	22	16	55	56	17.98	25.51*[d]
SD	0.43	0.47	18	21	12	11	11.50	17.20
n	32	29	32	29	32	29	32	29
Manikin								
M	1.80	1.89	11	13	91	94	30.07	29.66
SD	0.47	0.53	14	15	15	9	14.60	18.60
n	31	28	31	28	31	28	31	28

Time Wall[e]								
M	0.02	0.01	—	—	—	—	—	—
SD	0.03	0.01	—	—	—	—	—	—
n	32	29	—	—	—	—	—	—
Memory tests								
Digit Recall								
M	3.66	4.03	12	14	38	42	5.20	5.64
SD	1.30	1.40	14	22	18	21	2.80	3.10
n	31	27	31	29	31	29	31	29
Single Digit Substitution								
M	2.90	2.99	13	16	54	55	9.17	9.44
SD	0.60	0.70	12	16	24	18	4.70	4.30
n	32	29	32	29	32	29	32	29
Six-Letter Search								
M	4.58	4.34	9	9	82	79	13.00	14.00
SD	2.00	2.10	12	12	16	19	9.10	10.50
n	30	26	30	26	30	26	30	26
Reasoning tests								
Serial Addition/Subtraction								
M	1.40	1.46	15	16	77	81	27.91	27.20
SD	0.40	0.30	13	14	27	20	16.40	11.70
n	32	29	32	29	32	29	32	29
Encode/Decode								
M	23.20	25.70	2	7	81	74	2.28	1.76
SD	5.20	4.90	5	13	30	30	1.10	0.90
n	30	27	32	29	32	29	32	29
Logical Reasoning								
M	3.64	3.53	16	15	76	76	10.94	12.45
SD	1.00	1.30	18	14	21	19	4.20	6.70
n	27	27	27	27	27	27	27	27

[a]In sec. [b]Correct Per Minute is (No. Correct)/(Total Reaction Time). [c]Simple Reaction Time tabled value is Response Reaction Time. [d]The drug groups differed at baseline on this measure. [e]Time Wall tabled value is the absolute value of (Estimated Arrival Time – Actual Arrival Time)/(Total Fall Time).

*$p < .05$.

TABLE 5
Effect Sizes for Clothing Factor

Test	*Correct Response Reaction Time*	*Percent Lapses*	*Percent Correct*	*Correct Per Minute*
Reaction time tests				
Choice Reaction Time	0.65*	–0.16	–0.56*	–0.74**
Simple Reaction Time	0.40[a]	0.55*	—	–0.54
Tapping	0.28[a]	0.28	–0.67**[a]	–0.61*[a]
Wilkinson Four-Choice	0.27[a]	0.98***	–0.70**	–1.45***
M	0.65	0.41	–0.63	–0.91
Spatial tests				
Matrix-2	0.66*	0.58**	–0.09[a]	–0.78***
Manikin	0.56*[b]	0.21	–0.34[a,b]	–0.58*[a,b]
M	0.66	0.40	—	–0.78
Memory tests				
Digit Recall	0.05	0.11	–0.15[a]	0.00[a]
Single-Digit Substitution	0.59*	0.42	–0.38	–0.57*
Six-Letter Search	0.31	0.33	–0.53*	–0.67*
M	0.32	0.29	–0.46	–0.62
Reasoning tests				
Serial Addition/Subtraction	0.59*	0.66**	–0.56*	–1.04***
Encode/Decode	0.68*	–0.10	–0.41	–0.63*
Logical Reasoning	0.04[a]	–0.06	–0.21[a]	0.06[a]
M	0.64	0.17	–0.39	–0.84
Average (overall – unconfounded)	0.50	0.32	–0.52	–0.80
Average (significant only – unconfounded)	0.63	0.69	–0.61	–0.84

Note. Tabled values are the means for (Chemical Protective Clothing – Utility)/*SD*.
[a]Possible confounding due to the gloves. [b]Possible confounding due to the mask.
$*p < .05$. $**p < .01$. $***p < .001$.

Reaction Time Tests

Choice Reaction Time. For Correct Response Reaction Time, Percent Correct, and Correct Per Minute, there was an effect of clothing, $F(1, 52) = 4.92, p < .031$; $F(1, 52) = 4.99, p < .03$; and $F(1, 52) = 8.52, p < .005$, respectively. Participants wearing CPC had longer reaction times, were less accurate, and worked at a slower rate, with effect sizes of 0.65, –0.56, and –0.74, respectively.

Simple Reaction Time. Because this test has no accuracy measure, Response Reaction Time was used instead of Correct Response Reaction Time. For Response Reaction Time, there was an effect of exercise, $F(1, 47) = 4.43, p < .04$. For Percent Lapses, there was an effect of clothing, $F(1, 47) = 6.28, p < .016$, and of exercise, $F(1, 47) = 5.90$, $p < .019$. Participants wearing CPC had more lapses, with effect sizes of 0.55, and exercise participants had longer reaction times and lapsed more frequently, with effect sizes of 0.57 and 0.58, respectively.

Tapping. In this test, accuracy was determined by comparing the percentage of successful alternations with the number of failures to alternate. For Percent Lapses, there was an effect of exercise, $F(1, 52) = 9.20$, $p < .004$. For Percent Correct, there was an effect of clothing, $F(1, 52) = 7.50$, $p < .008$, and of exercise, $F(1, 52) = 9.76$, $p < .003$. For Correct Per Minute, there was an effect of clothing, $F(1, 52) = 5.51$, $p < .023$. Participants wearing CPC were less accurate and worked at a slower rate, with effect sizes of –0.67 and –0.61, respectively, and exercise participants had more lapses and were less accurate, with effect sizes of 0.63 and –0.60, respectively.

TABLE 6
Effect Sizes for Activity Factor

Test	*Correct Response Reaction Time*	*Percent Lapses*	*Percent Correct*	*Correct Per Minute*
Reaction time tests				
Choice Reaction Time	–0.11	0.17	–0.06[a]	–0.15
Simple Reaction Time	0.57*	0.58*	—	–0.63
Tapping	–0.28	0.63**	–0.60**	–0.17
Wilkinson Four-Choice	0.00	0.00	–0.05	–0.13
M	0.05	0.35	–0.33	–0.27
Spatial tests				
Matrix-2	0.11	0.78***	–0.26	–0.37
Manikin	–0.19	–0.07	0.08	–0.30
M	–0.04	0.36	–0.09	–0.34
Memory tests				
Digit Recall	–0.22	0.59*	–0.41	–0.44
Single Digit Substitution	–0.55	–0.21	–0.14	0.13[a]
Six-Letter Search	–0.15	–0.08	–0.29	–0.13
M	–0.31	0.10	–0.28	–0.29
Reasoning tests				
Serial Addition/Subtraction	–0.25	0.23	–0.21[a]	–0.29
Encode/Decode	–0.10	0.49*	–0.17	–0.50
Logical Reasoning	–0.07	0.62*	–0.05	–0.60*
M	–0.14	0.45	–0.11	–0.46
Average (overall – unconfounded)	–0.10	0.31	–0.21	–0.34
Average (significant only – unconfounded)	0.57	0.62	–0.60	–0.60

Note. Tabled values are the means for (Exercise – Sedentary)/*SD*.
[a]The activity groups differed at the baseline on this measure.
*$p < .05$. **$p < .01$. ***$p < .001$.

TABLE 7
Effect Sizes for Drug Factor

Test	*Correct Response Reaction Time*	*Percent Lapses*	*Percent Correct*	*Correct Per Minute*
Reaction time tests				
Choice Reaction Time	0.00	0.54	–0.30	–0.10
Simple Reaction Time	0.00	0.15	—	0.03
Tapping	0.28	0.33	–0.33	–0.27
Wilkinson Four-Choice	–0.10	0.25	0.00	–0.13
M	0.05	0.32	–0.21	–0.12
Spatial tests				
Matrix-2	0.11	0.31	–0.09	–0.53*[a]
Manikin	–0.18	–0.14	–0.24	0.02
M	–0.04	0.09	–0.17	0.02
Memory tests				
Digit Recall	–0.27	–0.11	–0.20	0.00
Single Digit Substitution	–0.14	–0.22	–0.05	–0.13
Six-Letter Search	0.12	0.00	0.17	–0.10
M	–0.10	–0.11	–0.03	–0.08
Reasoning tests				
Serial Addition/Subtraction	–0.19	–0.07	–0.17	0.09
Encode/Decode	–0.50	–0.51	0.23	0.63
Logical Reasoning	–0.10	0.06	0.00	–0.27
M	–0.26	–0.17	0.02	0.15
Average (overall – unconfounded)	–0.08	0.05	–0.09	–0.02
Average (significant only – unconfounded)	—	—	—	—

Note. Tabled values are the means for (Diphenhydramine – Placebo)/*SD*.
[a]The drug groups differed at baseline on this measure.
$^*p < .05$.

Wilkinson's Four-Choice. For Correct Response Reaction Time, there was an interaction of clothing, exercise, and drug, $F(1, 51) = 4.11$, $p < .048$. For Percent Lapses, there was an effect of clothing, $F(1, 51) = 17.90$, $p < .0001$, and an interaction of clothing, exercise, and drug, $F(1, 51) = 6.32$, $p < .015$. For Percent Correct, there was an effect of clothing, $F(1, 51) = 7.78$, $p < .007$, and an interaction of clothing, exercise, and drug, $F(1, 51) = 4.11$, $p < .048$. For Correct Per Minute, there was an effect of clothing, $F(1, 51) = 32.10$, $p < .000001$. Participants wearing CPC produced more lapses, were less accurate, and worked at a slower rate, with effect sizes of 0.98, –0.70, and –1.45, respectively.

Because of space limitations, interactions are described but not graphically depicted; they are presented elsewhere (D. Williams et al., 1995). There was an interaction of clothing, exercise, and drug correct on response reaction time. In the utility clothing condition, taking diphenhydramine increased reaction time for exercising participants and decreased reaction time for sedentary participants, whereas participants taking placebo showed decreased reaction time in the exercise group. This pattern of results was reversed for participants wearing CPC.

There was also an interaction of clothing, exercise, and drug on lapses. For participants wearing utility clothing, there was a small increase in lapsing caused by exercising or taking diphenhydramine. However, for participants wearing CPC, exercising participants lapsed less frequently when they took diphenhydramine in comparison with participants taking placebo, whereas sedentary participants lapsed more frequently when they took diphenhydramine.

There was an interaction of clothing, exercise, and drug on accuracy. For participants wearing utility clothing, exercising participants taking diphenhydramine were more accurate than were those who took a placebo, and sedentary participants were less accurate. For participants wearing CPC, exercising participants taking diphenhydramine were less accurate than were those taking a placebo. Sedentary participants showed no effect of drug condition on accuracy.

Discussion. Wearing CPC might produce performance decrements for two different reasons. First, performance decrements might result from cognitive impairments due to the psychological distress produced by wearing CPC. Wearing this clothing requires the user to force air through the respirator and to deal with possible claustrophobic feelings. Furthermore, the impermeability of the suit frequently results in uncomfortable air temperature and humidity inside the suit and increased subjective temperature. Coping with the psychological stress produced by wearing this clothing may lead to decreased cognitive performance. Second, performance decrements might be caused by physical limitations produced by wearing CPC rather than by cognitive impairment. These decrements might be caused either by the restricted visual range produced by the protective facial mask or by clumsiness produced by wearing heavy gloves while trying to make a single keystroke on the computer keyboard and could occur even if the participant were cognitively unimpaired.

The performance problems caused by the mask and gloves are operationally realistic for some situations. However, it is important to separate the relative contributions of psychological and physical problems because these problems allow different solutions. One way to separate the contributions of each factor is to estimate the size of the performance decrement produced by the physical constraints of the clothing. If the performance decrement is well beyond what would be expected from the physical problems, then a cognitive decrement can be inferred.

For example, the visual limitations produced by the mask could have affected cognitive performance. A study of the area of binocular vision for the M17A1 mask (McAlister, Buckingham, & Wingert, 1993) showed that a soldier wearing this mask would have an unrestricted visual field of only a 20° angle. Assuming a distance from the screen was 12 to 16 in. (30–41 cm), the participant would be able to see the information presented without making head or eye movements for all but the Manikin and Matrix-2 tests, which require a larger field of vision than the other tests. Thus, the visual characteristics of the mask probably did not affect performance for the majority of the tests.

Also, the clumsiness caused by wearing gloves might have affected reaction time, accuracy, and rate. This could interfere with finger flexion and would be expected to increase the reaction times. The average difference between CPC and utility clothing conditions in reaction time for tasks requiring little cognitive processing was 10 msec for Tapping, 20 msec for Wilkinson's Four-Choice, and 30 msec for Simple Reaction Time. Thus, if there were no cognitive effects due to wearing CPC, we would expect the difference due to wearing gloves to average 20 msec. When the difference in reaction times between participants wearing CPC and utility uniforms is much larger than that, it probably reflects genuine cognitive impairment.

The extent of the decrease in accuracy caused by the gloves can be estimated from the data for extraneous responses. For each task, only a few of the keys on the keyboard were acceptable response keys. Pressing a nonresponse key was recorded and triggered an auditory warning. Analysis of these extraneous responses for Choice Reaction Time, Simple Reaction Time, Tapping, and Wilkinson's Four-Choice showed that the average difference in the number of these responses between participants wearing CPC and utility clothing was less than 1%. This suggests that the clumsiness produced by wearing gloves had a minimal effect on the accuracy of the response unless the difference between the two groups was only a few percentage points. Of these tests, the only one that may have been substantially influenced by wearing gloves was Tapping because the accuracy difference between participants wearing utility uniforms and CPC was only 4%.

Rate of performance also could have been affected by the gloves. For Tapping, in which both accuracy and reaction time may have been affected by the glove, the rate likely was affected. For other tests, the effect of the glove can be estimated using previously obtained estimates of glove effects on accuracy at 1% and reaction time at 20 msec. The effect of the glove on rate, which is the number correct divided by the sum of the reaction times, was approximated by dividing Percent Correct by Correct Response Reaction Time. These estimates suggest that, for Choice Reaction Time and Wilkinson's Four-Choice, wearing gloves had a minimal effect on rate.

However, lapsing cannot be attributed to the gloves. For the three easy reaction time tests—Simple Reaction Time, Tapping, and Wilkinson's Four-Choice—lapses were defined as responses made 440 to 1,200 msec after presentation of the stimulus. A difference in this variable must reflect a cognitive decrement—presumably in the ability to sustain attention.

Wearing CPC resulted in a significant performance decrement on 10 of the 15 combinations of tests and dependent measures. For 6 of the combinations, it is possible some decrements in reaction time, accuracy, and rate occurred because of wearing gloves. However, for each dependent measure, there is at least one unconfounded statistically significant result showing cognitive impairment for participants wearing CPC. The effect sizes of significant results were in the moderate to large range.

Exercise moderately impaired performance on the reaction time tests. It increased reaction time for Simple Reaction Time, increased lapsing for both Simple Reaction Time and Tapping, and decreased accuracy for the Tapping. Diphenhydramine did not appear to affect the reaction time tests.

When the effect sizes for the results of the reaction time tests are examined without regard to statistical significance, the unconfounded results across the reaction time tests show that wearing CPC moderately impaired performance for reaction time, lapsing, and accuracy and produced a large decrement in rate. Exercise produced inconsistent effects for reaction time, and it produced small effects that increased lapsing and decreased both accuracy and rate. Diphenhydramine produced small effects, which increased lapsing and decreased accuracy. The effect size analysis suggests that effects of each stressor across the reaction time tests generally were to degrade performance.

Spatial Tests

Manikin. For Correct Per Minute, there was an effect of clothing, $F(1, 51) = 5.84$, $p < .019$. Participants wearing CPC worked at a slower rate, with an effect size of −0.58. For Correct Response Reaction Time, there was a Clothing × Exercise interaction, $F(1, 51) = 7.84$, $p < .018$. In the utility uniform condition, exercise participants had longer reaction times than participants who were not exercising. In the CPC condition, exercise participants had somewhat shorter reaction times than participants who were not exercising.

Matrix-2. For Correct Response Reaction Time, there was an effect of clothing, $F(1, 53) = 6.83$, $p < .012$. For Percent Lapses, there was an effect of clothing, $F(1, 53) = 7.81$, $p < .007$, and exercise, $F(1, 53) = 11.40$, $p < .001$. For Correct Per Minute, there was an effect of clothing, $F(1, 53) = 12.72$, $p < .0008$, and of drug, $F(1, 53) = 6.20$, $p < .016$. However, the effect of drug on rate must be discounted because the groups differed at baseline. Participants wearing CPC had longer reaction times, more lapses, and worked at a slower rate, with effect sizes of 0.66, 0.58, and −0.78, respectively. Exercise participants had more lapses, with an effect size of 0.78.

Time Wall. This task differed from the other tasks, and a different dependent measure was used. The task was to predict the arrival time of a falling object, which fell at different rates. The dependent measure used was the absolute value of the difference between the expected and actual object arrival time divided by the actual arrival time. There were no significant effects for this measure.

Discussion. Wearing CPC produced several performance decrements, which could be due to the physical limitations of the clothing or could reflect cognitive impairment. Both the Manikin and Matrix-2 tests require a larger field of vision than do the other tests. Given the visual restrictions of the mask, it is difficult to see the entire Manikin display in a single glance. Because this test requires using information presented at the edge of the display, the participants may have had to make eye or head movements to see the required information, which would increase reaction time. Consequently, the difference in reaction time for this test may have resulted from the reduced visual fields of the mask. However, at these distances, it would be possible to see most or all of the Matrix-2 display. Successful performance on this test is less dependent on peripheral information than is the Manikin test. Thus, the difference in reaction time for the Matrix-2 test is unlikely to be caused by the mask.

The increases in reaction time were much larger than those expected from wearing the gloves. For the Manikin test, there was a 240-msec increase; for the Matrix-2 test, there was a 330-msec increase. The change in reaction time for the Manikin test may be due to the restricted visual fields produced by the mask. However, the change in the Matrix-2 test is unlikely to be due to either the mask or gloves and probably reflects cognitive impairment.

Results of the Matrix-2 test suggest that soldiers wearing CPC may lapse more frequently. Because Lapsing is unaffected by the mask and gloves, these lapses reflect cognitive impairment.

Both Manikin and Matrix-2 tests showed moderate decrements in rate for soldiers wearing CPC. The increase in reaction time for the Manikin test may result from the mask, as may the decrement in rate. However, the Matrix-2 rate change likely indicates a cognitive decrement.

Exercise moderately increased lapsing in Matrix-2. Diphenhydramine produced no unconfounded effects.

The effect size analysis across the Manikin and Matrix-2 tests suggests that wearing CPC produced a moderate to large decrement in performance across spatial tests for Correct Response Reaction Time, Percent Lapses, and Correct Per Minute. The effects on Percent Correct could not be determined because of possible confoundings. Exercise produced a small increase in Percent Lapses and a small decrease in Correct Per Minute. Diphenhydramine showed negligible effects.

Memory Tests

Digit Recall. For Percent Lapses, there was a significant effect of exercise, $F(1, 52) = 6.47$, $p < .014$. Exercise participants made more lapses, with an effect size of 0.59.

Single Digit Substitution. For Correct Response Reaction Time and Correct Per Minute, there was an effect of clothing, $F(1, 53) = 4.18$, $p < .046$, and $F(1, 53)$

$= 5.66, p < .021$, respectively. Participants wearing CPC had longer reaction times and worked at a slower rate, with effect sizes of 0.59 and –0.57, respectively.

Six-Letter Search. For Percent Correct and Correct Per Minute, there was an effect of clothing, $F(1, 48) = 5.03, p < .030$, and $F(1, 48) = 5.89, p < .019$, respectively. Participants wearing CPC were less accurate and worked at a slower rate, with effect sizes of –0.53 and –0.67, respectively.

Discussion. With the exception of Digit Recall accuracy, the effect of the clothing condition in reaction time and accuracy was larger than the effect of wearing gloves. The effect of wearing CPC on memory test performance was significant both for Single Digit Substitution, in which there was an increase in reaction time and a decrease in rate, and for Six-Letter Search, in which there was a decrease in accuracy and a decrease in rate. Consequently, these performance decrements indicate a cognitive impairment.

Exercise increased lapsing on the Digit Recall test. However, diphenhydramine produced no effect.

The effect sizes analysis across memory tests suggests that wearing CPC produced small to moderate memory performance decrements. Exercise produced small decrements in reaction time, accuracy, and rate. Diphenhydramine effects on memory performance were negligible.

Reasoning Tests

Serial Addition/Subtraction. For Correct Response Reaction Time, Percent Lapses, Percent Correct, and Correct Per Minute, there was an effect of clothing, $F(1, 53) = 4.07, p < .049$; $F(1, 53) = 7.20, p < .01$; $F(1, 53) = 5.84, p < .019$; and $F(1, 53) = 16.05, p < .0002$, respectively. Participants wearing CPC had longer reaction times, made more lapses, were less accurate, and worked at a slower rate, with effect sizes of 0.59, 0.66, –0.56, and –1.04, respectively.

Encode/Decode. For Correct Response Reaction Time, there was an effect of clothing, $F(1, 49) = 5.62, p < .022$. For Percent Lapses, there was an effect of exercise, $F(1, 53) = 4.02, p < .05$. For Correct Per Minute, there was an effect of clothing, $F(1, 53) = 5.59, p < .022$. Participants wearing CPC had longer reaction times and worked at a slower rate, with effect sizes of 0.68 and –0.63, respectively. Exercise participants made more lapses, with an effect size of 0.49.

Logical Reasoning. For Percent Lapses and Correct Per Minute, there was an effect of exercise, $F(1, 46) = 5.18, p < .028$, and $F(1, 46) = 4.18, p < .047$, respectively. Exercise participants were more likely to lapse and worked at a slower rate, with effect sizes of 0.62 and –0.60, respectively.

Discussion. Because the magnitude of the increases in reaction time and the decreases in accuracy are far larger than could be caused by only wearing gloves, they probably reflect a cognitive decrement. The effects of wearing CPC decreased performance for all measures of performance of Serial Addition/Subtraction and decreased performance on Correct Response Reaction Time and Correct Per Minute for Encode/Decode.

Results also showed that exercise increased lapsing on both Encode/Decode and Logical Reasoning and moderately decreased the rate for Logical Reasoning. There were no main effects of diphenhydramine.

The effect size analysis across reasoning tests suggests that wearing CPC produced a small decrease in Percent Correct and a large increase in Correct Response Reaction Time and Correct Per Minute. Activity produced a moderate increase in Percent Lapses and a decrease in Correct Per Minute. Diphenhydramine produced a small improvement in Correct Response Reaction Time.

GENERAL DISCUSSION

Considering effects that are uncontaminated by physical problems produced by wearing the mask or the gloves, wearing CPC produced at least one statistically significant cognitive deficit in each category of test for the dependent measures of reaction time and rate. Additionally, there was evidence that lapsing and accuracy were affected for three test categories. The generality of the cognitive deficit is supported by the effect size analysis. When the effect sizes are averaged for all unconfounded results across the four categories of tests, the average effect of wearing CPC was a small increase in lapsing, a medium increase in reaction time, a medium decrease in accuracy, and a large decrease in rate.

The statistically significant effects of exercise were always to decrease performance—chiefly through moderately increasing the number of lapses. The effect of exercise depends on how strenuous the exercise is and how much exercise has been accomplished when the participants were tested (Tomporowski & Ellis, 1986). Because the exercise participants carried a heavy backpack for 18 to 24 miles (29–39 km) at the time our data were collected, they likely were past the invigorating part of the exercise. Their physical fatigue manifested in lapses on half of the tests. This has been observed before in sleep-deprived participants in response to more moderate levels of exercise (Angus, Heslegrave, & Myles, 1985). However, this variable is rarely used in exercise research. There also was evidence that exercise either increased reaction time or decreased accuracy or rate on three different tests. There was no significant performance improvement on any test. The effect size analysis showed a small average effect size increasing lapsing and decreasing accuracy and rate.

There were no unconfounded statistically significant main effects of taking diphenhydramine. Although there were individual effects that approached significance, the effect size analysis across the four categories of tests provided no evidence for a general effect.

The lack of general impairment due to diphenhydramine was somewhat surprising given the drug's reported effects of producing sedation and cognitive impairment. However, as previously mentioned, the majority of research on this drug investigated the effects of a single dose, rather than of multiple doses. Multiple dosing may have led to the development of tolerance. Previous research found no cognitive performance impairment by the 3rd dosing day (Schweitzer et al., 1994). The research presented here suggests that tolerance develops by the 2nd day of dosing. Data from the first 6 hr of data collection shows that average effect sizes for the first dosing interval were in the small range, but some effects were statistically significant. The attenuation of these already small effects may account for the relative lack of impairment seen in the data from the last 8 hr of the study.

Given diphenhydramine's relatively long half-life of 8.5 hr, the dosing interval, and number of doses, it is likely the participants' blood plasma levels approached steady state by the time of testing. If blood plasma is important in determining side effect severity (Carruthers, Shoeman, Hignite, & Azarnoff, 1978; Licko et al., 1986), tests from different batteries would be equivalently affected. However, if the participants' blood plasma levels fluctuated substantially, then the cognitive performance effects of diphenhydramine might only affect tests administered 2 to 4 hr postdosing, at the time of peak blood plasma. Because the sixth dose was given at noon during Block 4, participants would have achieved peak plasma levels between 1400 hr and 1600 hr, during administration of tests from Battery 2. Examination of the average effect sizes from these tests shows no further impairment during this battery, making it unlikely that cognitive performance decrements were produced by diphenhydramine for a limited interval, which was obscured by examination of effects from all three batteries of tests.

The stressors produced few interactions, and those interactions did not always suggest a synergistic effect of the stressors on cognitive performance. It might have been expected that the physical fatigue produced by prolonged moderate exercise combined with the sedative effects of diphenhydramine and the stress of being in CPC would be more than additive for our sleep-deprived participants. However, the dearth of interactions suggests the combined effects of these stressors can be estimated using an additive model. A lack of interactions among similar factors was also reported by Arad et al. (1992).

The conclusion that wearing CPC produces cognitive decrements not due to the clumsiness of the gloves or the visual limitations of the mask is a new interpretation. As mentioned previously, several researchers have reported a decrement in cognitive performance produced by this clothing (Englund et al., 1987; Englund et al., 1988; Kelly, Englund, et al., 1988; Kobrick & Sleeper, 1986; Rauch et al., 1986). However, these researchers interpreted these decrements as resulting from physical limitations produced by the clothing. The results presented here suggest that, even when the extent of these physical limitations is taken into account, wearing this clothing produces a moderate cognitive decrement in Marines who are experienced in wearing this clothing.

The degradations in cognitive test performance produced by wearing CPC mirror decrements reported for simulations of military tasks. Johnson, McMenemy, and Dauphinee (1990) showed that wearing CPC decreased accuracy by 15% on shooting pop-up targets presented by a Weaponeer marksmanship simulator. Hamilton, Folds, and Simmons (1982) found that helicopter pilots wearing CPC had performance decrements with effect sizes of 0.62 for maintaining heading and 0.46 for holding a constant airspeed. These errors are in the range of the errors seen in the cognitive test performance.

Similarly, the cognitive decrements produced by exercise mirror the military performance decrements seen following a 20-km road march carrying a 45-kg pack. Knapik et al. (1990) found decrements in marksmanship hits and distance from the target, with effect sizes of –0.72 and 0.68, respectively.

This report makes several contributions. First, because of the large sample size and the number of cognitive tests used, the data are more reliable and more representative of different cognitive abilities than previous studies of CPC. Second, this is the first report of dependent measures using empirically derived, sensitive measures that may be related to operational performance (D. Williams, 1995). Third, evidence is provided that the performance decrement caused by wearing CPC is not due solely to the physical effects of the clothing. Fourth, this is the first report of an increase in lapses in responding due to wearing CPC. Fifth, a general cognitive impairment caused by prolonged moderate exercise in sleep-deprived participants is demonstrated. Finally, this report shows that the cognitive deficit initially produced by ingestion of diphenhydramine has resolved after 1 day of repeated dosing.

Operationally, although decrements in accuracy, reaction time, and efficiency are important, the inability of soldiers wearing CPC or who have engaged in prolonged moderate exercise to sustain attention to a task may well be more important. These performance lapses produce a qualitative change in performance that could adversely affect performance on military tasks.

The results of this study suggest that sleep-deprived soldiers wearing CPC will take longer to do the task, even when lapses are not counted as part of task performance. They will have trouble maintaining attention to the task, and their performance will be less accurate. These cognitive decrements will result in less efficient cognitive processing. Sleep-deprived soldiers who perform prolonged physical work of moderate intensity will have trouble maintaining attention to the task, and they will be less accurate and less efficient. The results presented here suggest that, if sleep-deprived soldiers' jobs are near the limit of their cognitive abilities, and if they must wear CPC or engage in prolonged, moderate exercise, they may be unable to perform their job satisfactorily.

These results may also apply to other situations that require either wearing protective clothing or strenuous exercise. For example, firefighters and personnel involved in chemical spill cleanup may be similarly affected. If their work is intellectually demanding and requires them to stay in CPC for several hours, or if they are fatigued from exercise, their job performance may be compromised.

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The Impact of Chemical Protective Clothing on Military Operational Performance

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Wearing chemical protective clothing (CPC) while conducting military operations limits a soldier's dexterity, mobility, command and control, communications, and endurance. A series of field studies was conducted to identify mission degradations from the protective clothing on the chemically contaminated battlefield. The studies differed in complexity but had a common goal of comparing task performance and endurance of soldiers wearing the full protective ensemble versus wearing the standard military field uniform. This article summarizes 3 U.S. Army programs. One of them is called the Physiological and Psychological Effects of the NBC Environment and Sustained Operations on Systems in Combat. A review of 19 studies concerning combat, combat support, and combat service support systems shows that most military tasks can be performed satisfactorily while CPC is worn, but usually, extra time is required to perform such tasks. Higher ambient temperatures and high workloads are especially detrimental to endurance. Realistic training in the ensemble is deemed essential for sustaining performance on the chemically contaminated battlefield.

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Military operations on a chemically contaminated battlefield are likely to present special problems. Soldiers' performance can be degraded by wearing the required chemical protective clothing (CPC) ensemble. The mask and gloves are uncomfortable and compromise manual dexterity, vision, communication, personnel identification, and mobility. Compounding these problems is the potential requirement of wearing the ensemble for several consecutive hours. Another complication is "dual encapsulation," that is, wearing the ensemble while working in a microenvironment such as the turret of a self-propelled howitzer or a closed-hatch battle tank or personnel carrier.

The potential for performance problems was noted in a report entitled "Chemical Warfare: Soldiers Inadequately Equipped and Trained to Conduct Chemical Operations" (U.S. General Accounting Office [GAO], 1991). Partly based on a survey of 93 soldiers to assess whether the standards of chemical training policy were being met, the GAO concluded that the state of U.S. Army chemical training was inadequate for efficient military operations in a chemically contaminated environment. Because of shortcomings in training, problems would be expected in conducting sustained operations and in performing some tasks while the CPC ensemble was worn. In fact, the 1991 Persian Gulf War (Operation Desert Storm) reinforced the need to identify and overcome shortcomings in operational efficiency on the chemically contaminated battlefield.

Knowledge of the protective clothing ensemble's influence on soldier performance is gained from field testing, laboratory studies, and modeling. Field testing, "the conduct of experimentation or the evaluation of manned systems in a credible operational environment" (E. M. Johnson & Baker, 1974, p. 203), serves two important functions:

1. To establish credibility with commanders who must address the practical significance of the results. (Studies that employ scenarios consistent with how one will fight are more apt to be taken seriously by commanders.)
2. To identify deficiencies from realistic scenarios to help develop new doctrinal, organizational, leadership techniques, training, and matériel improvements. Whether such changes foster efficient operations on the battlefield can be verified in subsequent studies.

Three major programs investigate chemical defense issues through the use of field studies. The common focus is to examine the effects of wearing the full CPC ensemble (Mission-Oriented Protective Posture Level IV [MOPP IV]) versus the Battle Dress Uniform (BDU) on task performance (time and accuracy measures) in a variety of military scenarios. These programs are Joint Chemical Biological Contact Point and Test (Project DO49), Combined Arms in a Nuclear/Chemical Environment (CANE), and Physiological and Psychological Effects of Nuclear, Biological, and Chemical (NBC) and Extended Operations on Systems in Combat (P^2NBC^2).

Test results from these programs are used to develop guides for commanders and to influence the development of soldier clothing, equipment, and computer models that predict soldier performance and soldier well-being. The following sections outline the methodologies of the programs, summarize their key results, discuss the applications of the findings to soldier performance issues, and note constraints in interpretation of data from these types of field studies.

SUMMARY OF PROGRAM RESULTS AND APPLICATIONS

DO49

DO49 sponsors small scale, controlled field scenario tests that examine team performance of specific military tasks while soldiers wear U.S. military chemical protective ensembles. Examples of tasks were removal and replacement of an M60 tank power pack and transmission, repair of an M60 machine gun and an electronic circuit board, installation and tear-down of radio-teletype equipment, unloading and loading a HAWK antiaircraft missile, and infantry-route reconnaissance operations (Davis, Wick, Salvi, & Kash, 1990).

Results. In general, all military tasks tested could be accomplished in MOPP IV, but the time to complete tasks was often increased compared to the time to do them without wearing the ensemble.

Davis et al. (1990) summarized the operational task data from these DO49 experiments, as well as a series of Air Force chemical defense studies, by classifying the distribution of performance decrement factors (PDFs) from 756 tasks. (PDF is the time to complete a task in MOPP IV divided by the time to complete it in BDU.) The bimodal nature of the distribution suggested classifying the PDFs into a lower end of "not degraded" with a mean of 1.0 (range = 0.00–1.15), a middle "slightly degraded" area with a mean of 1.5 (range = 1.16–1.85), and an upper "moderately degraded" end with PDFs greater than 1.85. Twenty-one percent of the tasks fell in the not degraded category, 69% fell in the slightly degraded category, and 10% fell in the moderately degraded category.

Davis et al. (1990) then classified each task by the ability required to perform it. Using a 10-item taxonomy, Davis et al. differentiated outcomes based on the distribution of PDFs: Most tasks requiring communication, manual control skills, movement and coordination skills, or visual pattern skills had a slightly degraded PDF (1.16–1.85). For the 10% of tasks that fell within the upper end, moderately degraded zone (>1.85), precision control, manual control, and movement skills were most frequently associated with degradation. As an example, M109 breech block reassembly subtasks, requiring precision control skills, were associated with higher end PDFs.

Applications. In these small-scale, focused military scenarios conducted in relatively low-stress environments (except for some heat-load trials), all tasks could be performed by soldiers wearing the full ensemble, with 10% of the tasks moderately degraded as rated by Davis et al. (1990). Categorizing of task performance into zones and cross classification of the tasks by the abilities required to perform them provides a convenient means by which to estimate degradations of other tasks by their similarity of action or abilities. This PDF information functions as a guide for military commanders to estimate troop performance degradation for different tasks, abilities, or simple scenarios. Knowledge of the upper end PDFs allows pinpointing tasks or abilities likely to be affected while CPC is worn and leads to recommendations for focused training. The data also serve as inputs to predictive operations research models such as the Army Unit Resiliency Analysis (Sheroke & Klopcic, 1991) and wargaming models such as JANUS (U.S. Army TRADOC Analysis Command, 1992).

Methodology issue. In an extensive review of chemical defense studies, Taylor and Orlansky (1991, 1993) noted that training on these DO49 tasks in BDU typically was not conducted to stable baseline levels before formal testing of the treatment, that is, wearing of the full protective ensemble. Performance improved over trials, but assessment and interpretation of the exact contribution of protective clothing at MOPP IV to a decrement from BDU was often confounded by practice effects in each clothing condition. Assuming the practice effect is greater in the BDU condition, the lack of proper training before a study would likely lead to misleading estimations of the true impact of protective clothing on performance.

CANE

CANE involved large scale, tactical scenarios with both friendly and enemy units for durations up to 96 hr. Weapon systems were instrumented to collect data on direct fire events, which made real-time casualty assessment possible. Other measures of performance included time to complete specified tasks and subjective evaluations of their correctness and degree of completion. CANE was run in phases (I, IIA, IIB, and Close Combat Light), with each phase dealing with a different focus.

Phase I: Infantry platoons. The test plan for Phase I called for eight 40-man infantry platoons to participate in a 72-hr scenario of offensive and defensive operations in a baseline condition (BDU) and in a *simulated* nuclear–chemical environment, which included a 12-hr MOPP IV scenario on Day 2. The order of BDU and MOPP IV was varied to minimize the learning effects. Performance measures focused on aspects of leadership, communication, and combat efficiency and involved comparing the percent change of MOPP IV scores from baseline scores.

Key findings (Draper & Lombardi, 1986) were as follows:

1. *Command and control.* Two conclusions were reached: (a) Command and control (i.e., soldier performance at planning, directing, coordinating, and controlling forces and operations) degraded because of exhaustion of leaders, changes in leader attitudes (increased frustration, irritation, and impatience), and disorientation (land navigation problems); for example, when platoon leaders became simulated casualties, the next senior soldier properly assumed command less than 25% of the time, in part because of a lack of awareness that the leader had become a casualty; and (b) correct identification of leaders and other personnel was difficult in full MOPP IV, in part because the NBC masks cover the face and the overgarments had few identifiable markings (name tag and rank insignia).
2. *Communications.* Because of difficulty in understanding verbalizations through the mask and hood: (a) the number of radio calls increased, and (b) time spent on radio communications increased (e.g., 71% of calls for indirect fire were completed within 10 sec with BDU, but only 50% were completed as quickly with MOPP IV).
3. *Combat efficiency.* Four conclusions were reached: (a) Time to complete a mechanized infantry attack increased (37 min with MOPP IV vs. 20 min with BDU); (b) in general, engagement efficiency (hits plus near hits divided by shots fired) decreased with all weapon types; (c) acquiring and identifying targets were more difficult because of the reduced field of view when wearing the protective mask; and (d) reduced field of view and recognition problems contributed to a 20% fratricide rate from small arms fire, compared to 4% with BDU.

Phase IIA: Tank company teams. Each of two tank company teams with supporting elements engaged in two operations of 72 hr, one in baseline and one in a simulated nuclear–chemical environment (Mojecki et al., 1987). Each operation included three movements to contact, three attacks, and four defensive engagements. The 2nd day in the nuclear–chemical environment involved 12 hr continuously spent in MOPP IV. Comparison of the MOPP IV to baseline results on this day showed the following: (a) Seventy-four percent fewer targets were destroyed in attack mode, and 80% were destroyed in defensive mode; (b) effectiveness of antitank rounds (tank gun and missiles), as measured by kills per rounds fired, was decreased 60% in attack and 65% in defense; (c) attacks took 33% longer to conduct; (d) engagement of targets was 50% lower; and (e) the loss–exchange ratio (number of friendly vehicles destroyed compared to number of enemy targets destroyed) was 4.6 times higher in offensive engagements and 5.5 times greater in defensive engagement.

Phase IIB: Battalion level. In this test, two battalion task forces each engaged in two operational scenarios of 96 hr, one in BDU and the other in a simulated nuclear–chemical environment (U.S. Army Chemical School, 1989). Soldiers wore MOPP IV during each of 10 engagements in each operation (4 day attacks, 4 day defenses, and 2 night defenses). Results showed that, during attacks, battle synchronization was degraded while in MOPP IV compared to BDU because commanders had difficulty controlling the location of units, timing of operations, and maneuvering their forces. A main cause of these deficits was the scout units' difficulty in locating and reporting enemy positions because of the degradation in hearing, seeing, and communicating caused by the MOPP IV. As a result, engagements with enemy units were closer than desired and were characterized by fewer primary weapon rounds fired, fewer targets destroyed, and reduced survival of infantry fighting vehicles. During defensive engagements, a notable deficiency was a 95% increase in time to move to alternate battle positions, and scout operations were again degraded, leading to poor battle outcomes. Significant deficiencies in the performance of combat support and combat service support duties were also reported.

Close combat light. This phase involved each of three light infantry companies participating in separate 96-hr baseline (BDU) and 96-hr nuclear–chemical environment operations characterized by three night attacks and one day-long defensive engagement (U.S. Army Chemical School, 1993). In the latter operation, soldiers wore MOPP IV during all battles or about 6 hr per day. Key results were as follows:

1. Close combat light units in MOPP IV traveled more slowly, taking 36% longer than in BDU to reach the objective. They were also less effective in operating direct-fire weapons because of visual and hearing problems and the difficulty in using night-vision devices while wearing the protective mask.
2. Leaders experienced marked performance degradation. For example, they did not execute plans as effectively in the simulated chemically contaminated battlefield, they micromanaged and delegated less, and they slept less and were more fatigued.

3. The units' radio communications degraded because of the mask and hood, resulting in a 28% increase in the number of repetitions and clarifications of messages.

4. Fire support operations were degraded. For example, more grid location and gun setting errors occurred, fewer rounds were fired, and fire mission times were slower. The report noted the advantage of training under simulated chemical conditions to learn how to adjust to the unique environment. In doing so, the number of enemy vehicles "destroyed" increased over days, and the degradation in mission execution times for howitzer crews disappeared by the fourth day of the nuclear–chemical environment condition.

Applications. The four CANE phases summarized here show degradation in combat efficiency, command and control, and communications. Although most tasks could be completed in MOPP IV, they often took more time, and accuracy was often degraded. An important function of the CANE program was to assist in fixing deficiencies identified in CANE studies. Based on consistent results from all the CANE phases, leadership training for personnel involved in chemical operations and enhancement of command and control operations while MOPP IV is worn were judged to be critical items requiring improvement. These areas especially are being examined for ways to compensate for the impact of MOPP IV on operations and thereby improve chemical warfighting capability under NBC conditions.

Design and methodology issues. The changes in key performance measures should be considered within the context of these types of field studies. Because of the need to gain information under realistic battlefield conditions, CANE involved free-play, large-scale scenarios. Although large amounts of data were gathered by observers and instrumentation, the absence of a true design places some caution on result interpretation. Certain aspects of E. M. Johnson and Baker's (1974) extended definition of field testing apply here: "[Field testing] addresses real but messy problems; involves a lack of control over the conduct of the test; has multiple objectives; requires an eclectic methodological approach; [and] almost always involves a value judgement" (p. 212). The latter point is important in that, in Phase I, not all evaluators were experienced enough to provide quality subjective judgements of platoon activities (Draper & Lombardi, 1986). Also, Phase I was characterized by severe weather and data collection problems that limited usable data to only five of the eight platoons. In fact, failures in instrumented data collection occurred in each CANE phase (e.g., during Phase IIB, data on two attacks and two defenses were lost). All phases were characterized by relatively small sample sizes because of cost considerations. Data collector and evaluator fatigue was noted in Phase IIA. The worthiness of these multiple phase CANE results is the *repeated* demonstration of operational deficiencies in task performance during realistically scaled and conducted engagements.

P^2NBC^2

This program represents a "middle ground" between DO49 and CANE of more controlled scenarios involving specific military systems and the performance of military crews who operate them. Full encapsulation in MOPP IV, hot ambient environments, extended workdays (sometimes 24 hr or longer), and operations at night represent some of the typical stressors encountered in P^2NBC^2 studies. In addition to time and accuracy measures, psychological and human factors data were collected from interviews and test batteries administered periodically during a study.

Studies looked at the capability of Army units to perform combat, combat support, and combat service support operations. Examples of units studied include armor, artillery, mechanized infantry, NBC reconnaissance, air ambulance, battalion aid station, air defense, signal, aviation, smoke generation (used for obscuring, screening, or marking), decontamination, and maintenance. Results from the 19 P^2NBC^2 field studies conducted between 1985 and 1994 are summarized next (for more details on the scenarios, temperature conditions, training, and main dependent variables, see Headley & Cunningham, 1995).

Results—Endurance. Operating on the chemically contaminated battlefield requires great stamina. Reduced troop strengths will preclude quick or frequent replacement of crews. Hence, all soldiers must be capable of conducting operations for extended periods, and casualties must be kept to a minimum.

The P^2NBC^2 studies documented the effects of high ambient heat on soldiers wearing the full CPC ensemble during full field operations. Some examples of endurance problems are as follows:

1. NBC reconnaissance teams had difficulty completing 4.5-hr missions in ambient temperatures ranging from 75 to 95 °F (24–35 °C; Jarboe & Troutman, 1990).
2. M109 (self-propelled howitzer) crews could sustain firing missions for only 2 to 4 hr in approximately 90 °F (32 °C) temperatures (Headley, Brecht-Clark, & Whittenburg, 1989). In slightly milder temperatures, two M109 crews lasted only 1.5 to 2 hr, whereas a third crew completed its mission after 3.5 hr, but in unseasonably cool conditions (Zubal et al., 1993). Towed artillery crews were able to endure about 4 hr under conditions of relatively higher workload and mild ambient temperatures (74–81 °F [23–27 °C]; Zubal, Doss, & Thompson, 1996).
3. The endurance of armor crews ranged from 3.3 to 16.6 hr in 48-hr scenarios (Headley, Brecht-Clark, Feng, & Whittenburg, 1988).

4. Soldiers performing high physical workloads were particularly susceptible to becoming casualties, as witnessed by the dropouts in studies that focused on vehicle decontamination (Blewett et al., 1992; Blewett, Seitzinger, Redmond, Fatkin, & Banderet, 1993), smoke generation (Blewett, Ramos, Redmond, & Fatkin, 1993), and combination smoke generation-and-decontamination duties (Blewett, Redmond, Modrow, Fatkin, & Hudgens, 1994). The Blewett, Ramos, et al. study showed that endurance for as long as 6 hr is unlikely and that the ability to perform operations for long periods using a manual fog oil pump is decremented because of heat stress.

5. Seven of 12 patient-decontamination team members were withdrawn after about 2 hr during the study's hottest trial, which reached a high of 96 °F (36 °C; Blewett, von Fahnestock, et al., 1995).

Results—Performance. For the tasks and scenarios studied, several shortcomings of crews performing in MOPP IV compared to BDU were identified. Artillery crews required longer times to fire rounds (Headley et al., 1989; Zubal et al., 1993; Zubal et al., 1996). Difficulties in performing artillery operations were attributed to visual, dexterity, and bulk restrictions from the ensemble (Headley et al., 1989; Zubal et al., 1993). Air defense teams required that enemy aircraft be closer for detection and identification (D. M. Johnson & Silver, 1992, 1993). Installation tasks pertaining to mobile subscriber communications equipment took twice as long, and voice transmission of messages took 50% longer (Blewett, Redmond, Ramirez, & Harrah, 1993). Expected rates for processing contaminated patients at a battalion aid station were not met; for example, a maximum of 8 versus the standard 20 patients were processed per hour (Blewett, Arca, Stickel, Jones, & Rowan, 1990).

Some tasks in MOPP IV were accomplished without significant decrement on either time or accuracy measures, as exemplified by studies of mechanized infantry crews (Headley et al., 1988), smoke generation (Blewett, Ramos, et al., 1993), vehicle decontamination (Blewett et al., 1992; Blewett, Seitzinger, et al., 1993), litter-patient decontamination and helicopter rearming (Blewett, Ramos, et al., 1994), corps hospital decontamination operations (Blewett, Arca, et al., 1995), and armor combat service support operations (Perez & Chaudoin, 1990). Most of the tasks in these studies mainly involved gross motor skills as opposed to fine motor control (e.g., mount and dismount vehicle, perform tactical movements, operate manual pump, spray decontaminant onto a vehicle, carry a patient on a litter, cut contaminated clothes off patients, load a missile into the launch tube of a helicopter, and conduct combat resupply operations). In the Blewett et al. (1992) study, although desired processing rates for vehicle decontamination were met, the quality of task performance degraded due to incomplete vehicle decontamination.

The P^2NBC^2 studies strongly suggest that performance in the ensemble can be influenced by the following conditions and their interactions: the type of task involved, the level of metabolic energy expenditure, soldier fatigue when wearing the protective ensemble, acclimatization to high ambient temperatures, the ambient temperature and relative humidity, adherence to drinking water discipline, prior training time in MOPP IV, and time required to operate in MOPP IV (if the soldier does not know the duration the ensemble must be worn, additional psychological stress results). Knowledge and understanding of these variables have greatly influenced military doctrine, training, and matériel enhancements. Such influences are discussed in the Applications subsection that follows.

Results—Stress assessment. An understanding of the stress inherent in chemical defense scenarios may help to identify ways for soldiers to cope and endure longer and to achieve more acceptable levels of performance. A self-report stress assessment battery was implemented in recent P^2NBC^2 studies (e.g., Blewett, Ramos, et al., 1993; Blewett, Ramos, et al., 1994; Blewett, Redmond, et al., 1994). The degree of stress experienced by soldiers in the tests was assessed from responses to four short questionnaires administered before, during, and after the scenarios. Responses were evaluated by comparing them with data from referent norms that represent low, medium, and high levels of stress (for a description of the battery as well as administering and scoring procedures, see Hudgens, Malkin, & Fatkin, 1992).

As an example, the sensitivity of the battery to P^2NBC^2 field test conditions is demonstrated by a recent study (Blewett, Ramos, et al., 1994) with soldiers in MOPP IV conducting litter-patient decontamination procedures. The study was conducted on 4 summer days during which the ambient test conditions (mean wet bulb temperatures) were as follows: Day 1, 83.3 °F (29 °C); Day 2, 74.4 °F (24 °C); Day 3, 74.3 °F (24 °C); and Day 4, 74.5 °F (24 °C). Self-report stress perception measures were obtained 5 times each day. A significant correlation was found between negative affect scores and wet bulb temperatures obtained over the 20 measurement times (Pearson $r = .73$, $p < .001$). The sizes of the mean negative affect scores placed the soldiers' responses on the hottest day in the range of moderate stress relative to referent norm conditions, whereas their responses were not different from the no-stress referent protocol on the cooler days.

The stress battery is quick, noninvasive, inexpensive to administer and represents a fruitful source of data directly from the soldier. Quantifying the soldiers' stress perceptions provides a method of determining whether vulnerability to stress is a component of observed performance degradation.

Applications. As stated in its charter (Department of the Army, 1987), the P^2NBC^2 program was to

> provide planning and [identification of] operational risk factors to field commanders, to support development of training programs, to develop doctrine and organization, and to influence the design and acquisition of materiel to improve the capability to

> conduct successful combat operations on a battlefield where NBC weapons are extensively and continuously employed. (p. 1)

Some changes in Army *doctrine* might help to reduce certain adverse effects of MOPP IV and to maintain a minimum safe defensive posture for the current conditions and threat (Stokes & Banderet, 1997/this issue). The revised Army Field Manual on NBC protection (FM 3–4; Department of the Army, 1992) provides guidance for flexibility in U.S. Army MOPP policies. Operating in a MOPP III status (gloves carried, overgarment opened) would mean improved manual dexterity and less need for rest breaks because of buildup of body heat. For example, the mobile subscriber system operations would likely have resulted in less task time decrement if the scenario allowed a MOPP III status (Blewett, Redmond, et al., 1993). P^2NBC^2 results led to a doctrinal recommendation of using low hover and land-and-load techniques versus hoisting methods in air ambulance operations because of low contamination transfer and quicker evacuation times (Blewett, Jones, & Arca, 1991).

The importance of *training* is also made clear by the P^2NBC^2 results. The GAO report (U.S. GAO, 1991) noted that not enough emphasis was given to training in MOPP to prepare soldiers for operations on the contaminated battlefield. A beneficial experience-in-MOPP factor was seen in the D. M. Johnson and Silver (1993) Stinger air defense artillery study. Practice improves speed and accuracy in performing military duties, but characteristics of the ensemble degrade time to perform many tasks. Proper training in MOPP can be important in other ways to enhance performance. Depending on the type of task or skills required to perform a job, improvising to facilitate performance is often necessary, such as learning to use a pencil to press keys or attaching name tags on the backs of ensembles for identification purposes. As noted by Headley et al. (1989), it is important that soldiers learn "how to conduct business" (p. 514) in MOPP before the protective ensemble must be worn for operations. Once soldiers learn they can operate in the ensemble, its annoying features become less important to the wearer and interfere less with performance.

The P^2NBC^2 data suggest that *endurance* can be increased by adherence to the guidance in FM 3–4 concerning work–rest periods and water requirements, as functions of ambient temperature, MOPP level, and physical work rate. Examples of this are mechanized infantry crews who completed a 60-hr, multitask scenario by taking reduced MOPP status breaks every 6 hr (Headley et al., 1988), and corps hospital decontamination teams working in shade, taking hourly rest breaks and a lunch break, and observing water discipline (Blewett, Arca, et al., 1995). The solution of portable personal cooling systems offers promise as shown in the Blewett, Ramos, et al. (1994) study, although issues of weight, comfort, fit, and equipment noise remain to be solved. The Jarboe and Troutman (1990) study demonstrated the importance of an adequately cooled vehicle to permit sustained operations. P^2NBC^2 data have been aggregated and applied to models that provide reliable prediction of heat strain. These models and tactical decision aids (e.g., P^2NBC^2 Heat Strain Decision Aid; McNally & Berndt, 1993) are also being reviewed by NATO allies for use by their forces.

Design and methodology issues. Results from the P^2NBC^2 studies must be evaluated in context of scenario constraints (Headley et al., 1989): (a) Typically, the duration of the scenario is known to the test participants; (b) participants are volunteers who have signed informed consent statements and are free to withdraw from the scenario at any time; and (c) the performance imperatives of real battle are missing—there was no live fire, the "contaminated" battlefield was simulated, and true sights, sounds, fear, and battle fatigue were missing. However, although the study scenarios do fall short of actual combat, performance effects were found.

The field studies were conducted under a variety of study designs, weather conditions, training on tasks, and adaptation time to the protective ensemble. Within a given study, differences in temperature, training, and experience could limit MOPP comparisons: Ambient temperatures for crews in BDU were sometimes different for those tested in MOPP IV. Inadequately trained crews yielded MOPP effects that were influenced by learning effects. Also, for some soldiers, participation in a study was the first real experience with chemical defense gear. To minimize many of these confounding effects, crews should be trained to predefined skill levels in BDU, and multiple trials should be investigated to look at performance changes over time (see Taylor & Orlansky, 1993).

In some studies, the experimental designs only resulted in descriptive statistics rather than parametric statistics, thereby limiting interpretation and generality of the data. Additional limitations also resulted because costs necessitated relatively small numbers of trials and sample sizes.

DISCUSSION

Wearing CPC as a defensive posture during chemical warfare can lead to soldier performance and endurance problems. All aspects of the ensemble are potential causes of deficiencies in mission capability. Forcing soldiers into MOPP IV produces problems in command and control, communication, and tasks requiring fine motor coordination. Time to complete many tasks is increased, and depending on temperature and workload, the duration of safe operations may be decreased.

Studies from the DO49 project showed that speed–accuracy trade-offs are usually made by soldiers in MOPP IV who achieve accuracy at the expense of completion time. Sixty-nine percent of tasks fell within the "slightly degraded" category, and given that the average performance decrement factor was 1.5, this value might be construed as a general degradation factor for these kinds of tasks. The U.S. Army's CANE program noted soldier difficulties not only in combat efficiency (both attack and defensive operations) but also in command and control, communication, and identification. The P^2NBC^2 program found many deficiencies in the ability of crews to perform system-specific tasks during a variety of operational conditions. If time to perform a task is not critical, then ensemble-induced increases are not likely to be militarily significant if the task can be performed to standard. However, many scenarios will not allow delayed reaction, such as for field artillery support, direct armor fire, vehicle decontamination procedures (slow processing times can lead to queue buildup), and command and control operations. Thus, although most tasks can be performed while wearing MOPP IV, maintaining accuracy at the expense of time is not always tolerable.

Clearly, sustained military operations during stressful ambient heat or under high workload will be problematic. Leadership will be an important factor in endurance by enforcing appropriate drinking water discipline, work–rest cycles, and crew rotations (cross training). A key finding, common to all the studies, is that training in MOPP IV for extended periods allows the soldier to acclimate and develop behavioral compensations that will extend endurance. This is a central message to commanders from the efforts of these programs. Experiencing the potentially degrading factors of the protective clothing ensemble and learning how to perform tasks in it can reduce some of the deficits. Because the contaminated battlefield is a likely future battlefield condition, training in MOPP IV is as essential as training during similarly adverse conditions of darkness or bad weather. Leaders should instill the confidence in their soldiers that they can survive and fight to win on the chemical battlefield. Increased training in MOPP IV will reinforce this confidence and improve task performance and endurance in this full protective ensemble.

However, a fuller understanding of the impacts of stress, motivation, and adaptation is needed to increase endurance of the individual soldier in MOPP IV. One issue is that of predicting which individuals are susceptible to heat stress while wearing CPC. Another issue is the apparent importance of psychological factors relating to the casualty phenomenon in many P^2NBC^2 field studies. Review of several recent studies (Redmond, 1993) indicates most casualties (both self-withdrawals and physician-directed withdrawals) occur before participants exceed physiological safety criteria (e.g., a participant is to be immediately withdrawn if core body temperature reaches 103 °F [39 °C]). Psychological data indicate significantly higher perceptions of stress for casualties than for those who do not become casualties (Hudgens, 1993).

The dynamic world political climate suggests that the threat of a chemical battlefield will continue. Continued attention to such issues has important implications for future equipment design, training, and doctrine regarding operations in NBC-contaminated environments. Research efforts and results from these three programs will help maintain a ready and capable defensive force.

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Modeling Military Task Performance for Army and Air Force Personnel Wearing Chemical Protective Clothing

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This article provides a short discussion of several models used to develop predictive techniques to study soldier performance while personnel wear chemical protective clothing (CPC). Discussed are U.S. Air Force and U.S. Army efforts in support of modeling of soldier performance in combat in a chemical environment. After several years of computer model development, a taxonomy was developed with a focus on human abilities impacted by wearing CPC. The potential application of this taxonomy for predictive modeling of CPC effects is described. This article also describes the scope of a computer accessible database of over 5,000 records, developed in support of the U.S. Army Program: Physiological and Psychological Effects of the Nuclear/Biological and Chemical Environment on Systems and Sustained Operations (P^2NBC^2). The database contains data from field studies for combat modeling efforts to support specialty areas such as operations, training, new protective garment evaluations, or MANPRINT analyses.

THE CHEMICAL THREAT

Chemical protective clothing (CPC) is designed to prevent casualties caused directly or indirectly by chemical agents disseminated in vapor, liquid, or aerosol form. Combat in a theater with chemical weapons presents threats and risks in varied ways. For example, chemical agent vapor is carried downwind, whereas liquid

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agent settles on the ground or on other objects (e.g., on soldiers and equipment). Evaporation of surface liquid agent near the attack site can also pose a secondary vapor threat.

The rates of absorption and evaporation of a liquid agent determines its persistence. The explosive dissemination of chemical agents is most effective when detonation occurs 10 m or less above the ground. Low-altitude detonation creates a dense vapor and liquid cloud, which directly affects personnel in the area and is a further threat downwind. The location and size of the affected area depend on the direction and speed of the wind. Liquid agent may also be driven into the ground with considerable force by an explosion, producing contaminated craters. When this occurs, chemical agents can become embedded in the ecosystem, contaminating vegetation and water supplies for months (Cole, McNally, & Monteith, 1988).

PROTECTIVE POSTURE RESPONSES

In a scenario employing chemical agents, U.S. troops would perform their duties in some combination of Mission-Oriented Protective Posture (MOPP) dictating up to four different levels of protection utilizing the Battle Dress Overgarment. The basic MOPP configuration means merely carrying all the CPC equipment, whereas in MOPP I, the suit is worn unzipped, and the other equipment is carried; in MOPP II, the suit is worn unzipped, and the boots are worn; in MOPP III, the suit is worn unzipped, boots and mask are worn, and gloves are carried; and in MOPP IV, the suit is zipped and closed at hands and at ankles and boots, mask, hood, and gloves are worn for complete encapsulation in the protective clothing system.

When contaminated by vapor only, the soldiers may spend a relatively short time in MOPP IV. However, when contaminated with liquid agent, the potential transfer hazard to skin may require encapsulation in MOPP IV for several hours (12 hr or more). Understanding the dynamics of wearing the protective clothing facilitates awareness of the problems encountered by personnel who must endure encapsulation in a combat environment. Predictive models must reflect these problems to quantify operational changes on the battlefield caused by the interaction of the soldier's clothing and her or his performance.

HISTORICAL REVIEW

Army Timeline

Several political events contributed to a perception that the United States no longer needed to maintain a high level of preparedness to fight on a nuclear, biological, and chemical (NBC) battlefield. First, in 1925, the United States signed the Geneva

Protocol treaties prohibiting the first use of bacteriological and chemical methods of warfare. Beginning in 1969, the U.S. stockpile of bacteriological agents was intentionally destroyed. During the early 1970s, U.S. Army threat assessment and planning assumed that a major war would be fought in Europe with conventional and nuclear weapons but probably not chemical–biological (C–B) weapons (Parks, Sanches, & Sullivan, 1982). The United States paid little attention to intelligence that the Soviets were preparing to fight using chemicals in conjunction with conventional and nuclear weapons because U.S. attention during this time was primarily focused on the conflict in Vietnam.

Soviet combat equipment captured in October 1973 from the Arab–Israeli War provided evidence that the Soviets were preparing for C–B conflicts. Soviet equipment, designed with built-in features for fighting in a chemically and radiologically contaminated environment included collective personnel protection, particularly inside vehicles. Several Soviet weapons were equipped with built-in radiological detectors and automatic measures for protection and operation in a NBC environment. A study was initiated by the United States to determine the C–B fighting capabilities of the Soviet Union and other adversaries.

The integrated NBC and conventional battlefield became a reality at the Nuclear Systems Program Review in 1972, when the U.S. Army Chief of Staff stated that, henceforth, the U.S. Army would be prepared to fight on an integrated battlefield, on which nuclear, chemical, conventional weapons, and electronic warfare would be used. In 1974, the U.S. military began the slow matériel development process leading to a capability to fight on a NBC battlefield. The participants developed a concept paper entitled "Biological and Chemical Survivability Criteria for Military Equipment." During development of the concept paper, the U.S. Army Nuclear Chemical Agency added concerns over residual nuclear effects. The concept paper stated that, to survive on a NBC-contaminated battlefield, three features of military systems were essential:

1. *Decontaminability:* The ability of a system (which includes weapons, equipment, and clothing) to be rapidly decontaminated or cleaned to reduce the hazard to personnel operating, maintaining, and resupplying it;
2. *Hardness:* The ability of a system to withstand the damaging effects of NBC contamination and any decontamination agent removal procedures; and
3. *Compatibility:* The ability of a system to be operated, maintained and resupplied by personnel wearing the full NBC protective clothing.

Air Force Timeline

During an analysis of the U.S. Air Force Chemical Warfare Defense program, it became apparent there were no reliable data regarding the increased times ground crews required to accomplish their tasks while wearing CPC. To overcome this knowledge gap, field testing was conducted at Moody Air Force Base, Georgia, in November 1980. The first study to document the effects of wearing CPC on the time it takes to perform Air Force tasks (compatibility) was accomplished by Cox, Jeffers, and Mascarella (1981). Although the scope of this test was relatively limited, it provided the Air Force with the first quantitative data of this kind in a dedicated, controlled situation. No heat stress effects were measured because the Air Force assumed an enemy threat scenario for a northern European environment. Test periods were relatively short and designed for a limited set of operations. Test results provided information concerning degradation of performance of Air Force ground-support personnel in MOPP IV for aircraft refuel, ammunition buildup, and aircraft quick-turnaround maintenance activities.

The results surprised the Air Force, which had believed most degradation would come from heat stress, not from the encumbrance of the bulky CPC suit, gloves, boots, mask, and hood as the study demonstrated. However, the analysis showed that the degradation in task performance varied with crew experience. Also, performance of routine tasks required between 50% and 70% more time when wearing MOPP IV. Other findings showed that the CPC impeded performance of manual-dexterity tasks required for aircraft preparation for return to battle (turnaround) and that, when problems were encountered in performing many tasks in MOPP IV, they were not easily correctable.

At about the same time, a chemical warfare defense exercise in a European scenario, SALTY MACE, was conducted at Hahn Air Force Base, Germany (U.S. Air Force, 1981). This exercise was designed to identify problems of a typical U.S. Air Force main operating base in Europe while conducting a wartime mission in a simulated chemical environment lasting 12 hr as part of a larger readiness exercise. The scenario presented two airfield attacks of conventional munitions and then three to five SCUD missiles with a simulated persistent chemical agent. The test demonstrated that the Air Force was not ready for even one chemical attack, much less the more probable two or three expected in a NBC combat environment. Test participants exhibited inexperience in responding to a chemical attack, awkwardness with donning and doffing protective gear, and degradation of task performance when wearing protective clothing.

Following SALTY MACE, the U.S. Air Force began including chemical defense preparedness as part of readiness exercise scenarios. Because U.S. Air Force ground facilities are stationary, the impact of a chemical threat could last days or even weeks because of the difficulty in moving to another area that would accommodate a military airstrip. In the mid-1980s, the U.S. Air Force began to focus on operational performance in a chemical environment and initiated an aggressive program to change the task procedures when in MOPP IV. The U.S. Air Force developed equipment such as the Multiman Intermittent Cooling System, changed workloads for highly physical tasks, hardened collective protection, and designed an airbase chemical detection and warning system. Today, the U.S. Air Force is well prepared for a chemical agent threat scenario.

SALTY MACE and other exercises performed by the U.S. Air Force during the early 1980s provided data on the problems with the use of chemical protective gear per se. The data collected from Army and Air Force field exercises provided the operations research and combat modeling community with information for the development of simulations and models to study problems encountered with the use of NBC protective clothing. The following section provides an overview of the development of the methodology used to model human performance when soldiers wear protective clothing on an integrated battlefield.

METHOD

Combat Modeling Development of the Chemical Environment

In 1975, BDM Corporation's Combined Arms Research and Analysis Facility reviewed the literature on changes in combat proficiency caused by wearing any protective clothing or masks. Information on target acquisition, probability of hits on a target, rate of fire, movement rate, responsiveness to communications, and time required to perform military activities was evaluated for model database development. The researchers found very little difference in operations when wearing Battle Dress Uniform and MOPP IV. Performance degradation was greatest for visual tasks (Fine & Kobrick, 1985). Selected computer models were used to determine the effect of MOPP gear on combat performance in a chemical environment. A discussion of the basis for the models used today is provided next.

SUMMIT and DEGRAD Models

The SUMMIT model incorporated degradation factors into an Index of Comparative Firepower representation (Burroughs & Williams, 1975) to account for the reduction in mission effectiveness of units forced to adopt various protective postures. The main equations in SUMMIT produced a Mission Degradation factor, which is the ratio of the effective strength of a military unit (company, battalion, brigade, etc.) to its overall potential strength. Twelve clothing systems were represented and evaluated in the model. These ranged from the summer combat uniform to MOPP IV with the ballistic vest. The decrement in the physical activity portion of the model was the diminished dexterity resulting from wearing protective gloves and the impaired vision resulting from wearing the protective hood and mask. These equations were based on very little experimental data because few were available when the modeling began.

SUMMIT was developed for use in the Mandrake Root Addendum Study in 1976 but was not used because it was not verified by the test data gathered at the Mandrake Root Field Test. This model addressed the combination of heat and respirator burdens in two ways. One technique was an estimate of the maximum time a soldier could work at a specified level of activity with a required rest period for the body to recuperate (work–rest cycles). The other method was an estimate of the fraction of time (averaged over an indefinitely long period) a soldier could work at an activity level, provided rest periods of prescribed length were incorporated within the work periods. This model was inaccurate to predict the time to perform tasks when wearing CPC; therefore, an independent model was developed that eliminated the heat and respirator burdens. The physiological and metabolic effects of various tasks also remained difficult to model because there was no empirical relation between metabolic rate and actual operational tasks performed by the soldier. Finally, the SUMMIT model excluded the dependence of combat units on artillery support because the results were still too severe and because these data did not match what occurred during field studies. Even after modifications, the SUMMIT model still predicted the combat units would be no more than 30% effective on a chemically contaminated battlefield, which was an unacceptable and implausible degradation of mission effectiveness. BDM Corporation next implemented the Degradation Assessment (DEGRAD) model to iterate the effects of MOPP in a war-game environment. The DEGRAD model was developed to modify SUMMIT, making it easier to use and reducing the overestimate of degradation that SUMMIT predicted.

The disparity between what was occurring in the SUMMIT model and actual soldier performance was later defined as *task workaround.* Soldiers in the field studies decreased the time for task performance by changing physical and cognitive workload to "work around" the problems caused by the CPC. However, the model did not allow such changes, hence the difference in performance between field studies and the modeled environment.

COMCAD III Model

BDM Corporation also developed an approach to modeling degradation in the Combat Capability Degradation (COMCAD III) model that did not attempt to assess degradation as an artificial chemical "lethality" added to that inflicted by conventional weapons. Prior models that forced degradation into a model not designed to accommodate the MOPP gear degradation effects proved to be incorrect and very difficult to quantify and validate.

The COMCAD III battlefield environment simulation was essentially a basic processor into which a set of parameters was specified to define the enemy target and the battlefield conditions. Scenario parameters, such as unit missions and movements, enemy attacks, and responses of units to those attacks, included C–B assessments of individual units' time to initiate and complete decontamination operations and to alter their MOPP levels. Chemical and biological lethality computations within COMCAD III were derived from the Chemical Casualty (CHEMCAS) methodology, which simulated the effects of a toxic environment on humans.

Heat exhaustion and heat stroke were assessed using the Heat Casualty (HECAS) methodology (BDM, 1975) based on the Givoni–Goldman heat stress model (Givoni & Goldman, 1972). In addition to casualties from the toxic agent and protective posture, COMCAD III assessed other personnel performance decrements. Such decrements resulted from interactions between the individual and the protective clothing (e.g., auditory, visual, and tactile) and environmental stresses imposed on the individual (e.g., lack of water and food). COMCAD III also assessed the impact of reduced availability of personnel and matériel on the toxic battlefield (e.g., withdrawal and time for decontamination, increased resupply and repair times). Finally, the impact of providing medical aid for mass casualties was evaluated. Portions of the CHEMCAS and HECAS models are still used today.

An overview of the models and their evolution to support the research is presented for the U.S. Army in Figure 1 and for the U.S. Air Force in Figure 2.

Impact on Mission Effectiveness

In 1980, the U.S. Army Human Engineering Laboratory (Carr, Jackson, Corona, & Bachovchin, 1980) critically assessed programs concerned with the field and laboratory testing of performance while soldiers wear CPC. This review was to identify gaps in the data and to help prevent redundant testing. Ten tests selected from 1959 to 1979 illustrated several data gaps. No data were available for any specialized type of combat, other than an amphibious assault in a tropical environment. Although many studies examined physiological effects of heat when wearing MOPP gear for temperatures from 70 to 90 °F (21–32 °C), there were no data on effects of wearing MOPP in cold weather or at night. The terrain in most of the tests was average, that is, flat to slightly hilly; no data were obtained for operations in mountains or jungle terrain.

In 1983, a test performed at Fort Hunter Liggett, California reported that wearing CPC had adverse effects on performance of infantry tasks. Vision was reduced because of mask fogging, and all motor movements were slowed and encumbered. Of interest were the human-factor comments made by the soldiers after the tests (Draper & Lombardi, 1986). Seventy-seven percent of the soldiers stated they pulled off their masks off at least once during the test because of frustration or anger.

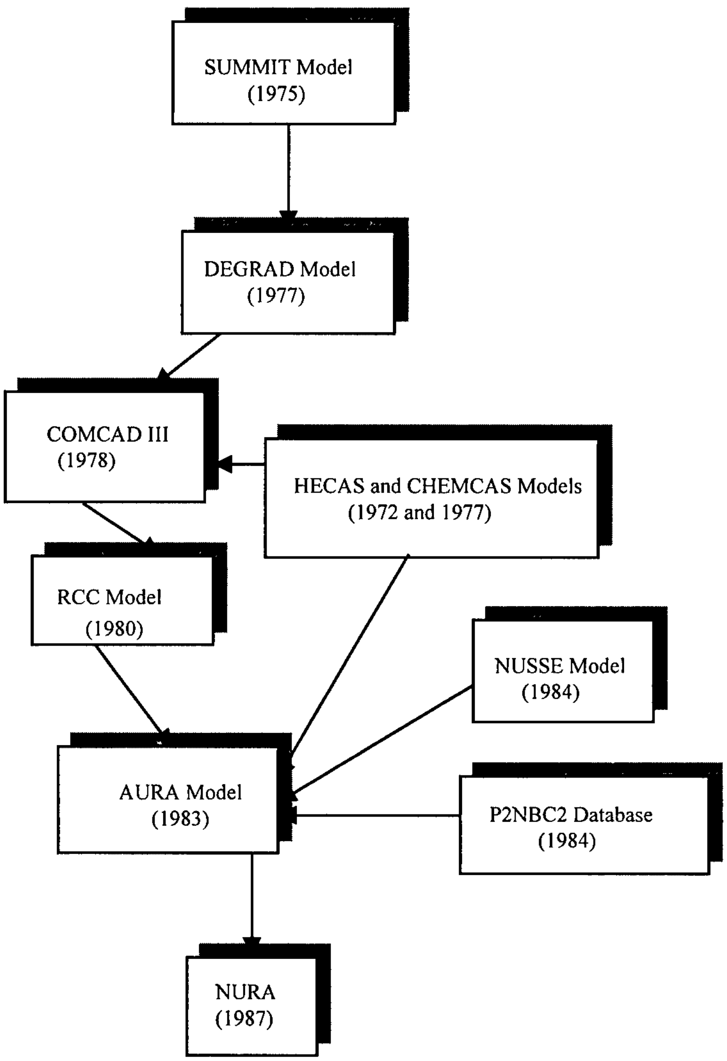

FIGURE 1 Army model development road map.

Twenty-eight percent of the soldiers indicated they pulled off the mask several times, and 17% stated they pulled the mask off and never put it on again. The large percentage of soldiers removing their masks suggests they experienced psychological stress, discomfort, and difficulty performing their missions. This same pattern of removing the mask was witnessed with soldiers during field exercises into the 1990s. When tasks are highly physical, the filter system of the mask makes it difficult for the wearer to inhale enough air to keep up with the physical demand required. The soldier slows down, increasing the time required to complete tasks; this is a persistent problem that will not be easily resolved.

Another review concerning the degradation of individual soldiers and units wearing the CPC was by Kerlin and Rolfe (1983). This evaluation of field tests, exercises, models, and studies was performed to gather data for prediction of performance degradation of soldiers wearing CPC. A data gap still existed because attempts were made to incorporate data from small exercises by aggregating what was available and using it with higher echelon simulation models of corps- or theater-level combat. Even with the analysis restricted to the smaller unit level, the data from field studies were unsatisfactory. No adequate modeling methodology existed to aggregate the impact of degradation from small military units to larger parent units (battalion, brigade, division, etc.). Not only are test data for large units expensive and difficult to acquire but the number of personnel contained in a large model makes it difficult to specify all the trade-offs of people and missions possible within the various units. Such challenges and concerns were the impetus for the U.S. Army Combined Arms in Nuclear and Chemical Environments series of field studies.

Before 1983, most data collection efforts relied on subjective weighting from experts to aggregate the total degradation stemming from different causes of soldier performance impairment. However, few models were available that portrayed small unit missions and operations in detail, models that generated a history of the unit's

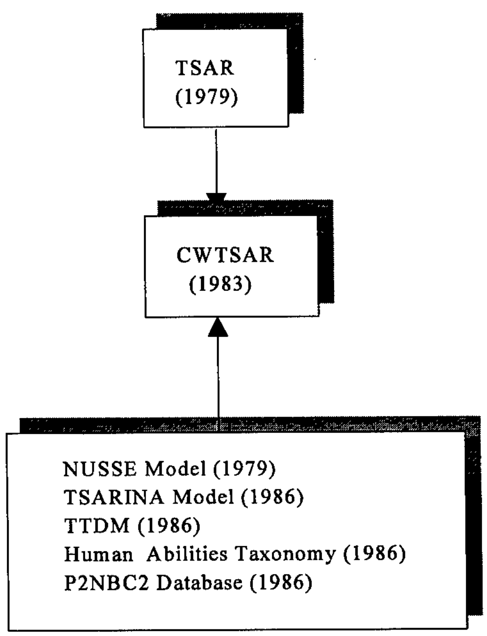

FIGURE 2 Air Force modeling road map.

effectiveness over time, which is essential for full understanding of the degradation issue. Nonetheless, these models required substantial preparation time and long computer run-times to complete the simulation and provide results for analysis.

In the early 1980s, the database was grossly inadequate to characterize performance degradation effects for ground and air units forced to fight in a toxic chemical environment to determine the impact on corps- or theater-level operations. It was difficult to compare 1980s data to the 1970s test data, because, as a whole, 1970s data were mostly qualitative and anecdotal rather than quantitative. The varied environmental conditions, different organizations conducting the tests using different collection methods, various levels and types of protective clothing, and different goals of each test made it very difficult to do anything more than treat each test as unique. Because there was no coherent structure or scheme behind each test, the test results were disjointed. In fact, some field studies (Stricklett, 1987) found certain tasks were performed better when in the MOPP IV due to the slightly elevated body temperature when wearing protective garments. Other studies reported the effects of fatigue and nonresponsiveness to orders because of the physiological stress due to the heat of wearing CPC (Tilley, Crone, Leake, Reed, & Tanaro, 1985). The development of a specific structure and design for the study of human performance in CPC testing did not occur until the mid-1980s with the onset of the U.S. Army program Physiological and Psychological Effects of NBC on Systems and Sustained Operations (P^2NBC^2; Wick, 1987).

AURA Model

The Army Unit Resiliency Analysis (AURA) model (Klopcic, 1988; Klopcic & Roach, 1984) evolved from an earlier model called Residual Combat Capability (RCC), a unit-level (i.e., squad) model. The RCC methodology was integrated into the COMCAD III model. Both models assess residual combat capability of a military unit before and after engaging in a series of hostile activities. The RCC model was appropriate for analyzing units at the company level but was a one-sided model because it permits an enemy to suffer an attack but does not allow the enemy to engage the attacking unit.

To evaluate the residual combat capability of any military unit for RCC, a functional analysis of those units assets and capabilities (links) integral to the performance of a given mission was required. Essential to this analysis was a thorough understanding of the mission, the military job specialty, the skill levels required, degradation of unit capability due to substitution of cross-trained personnel, and the time required to effect the substitution. Other aspects considered were the performance of personnel, equipment, or both as well as the interactions among these factors.

A problem with this model was that an analysis required detailed knowledge of a functioning unit and various ways of engaging that unit. Performing the functional analysis of a unit was a complex task requiring substantial time and effort. When the mission of a single unit is multiplied by different missions, different scenarios, different attacks with different defense postures, and different types of units, the overall task of producing a representative set of RCC results was a formidable challenge. The RCC model did not allow for entering the loss of effectiveness of personnel due to chemical protective measures and MOPP levels, a limitation due to the model's not being originally designed for efforts in a toxic environment.

In 1984, this was remedied for the AURA model with data collected during the Chemical and Biological Joint Contact Point and Test Program (Project DO49) supported by U.S. Army Dugway Proving Ground, U.S. Army Material Systems Analysis Activity, and U.S. Army Training and Doctrine Command. Dugway Proving Ground, assisted by the U.S. Army Ballistic Research Laboratory, conducted five tests (Armor Operations, Maintenance Operations, Missile Operations, Night Reconnaissance Operations, and Signal Operations) to measure mission degradation associated with CPC. The data from the five tests formed the basis of the AURA performance degradation data set. These studies provided data on individual and platoon-level tasks while wearing MOPP IV. Performance on several tasks showed statistically significant degradation when accomplished in MOPP IV. It was also determined that increased operating experience (i.e., training) in MOPP IV resulted in a significant reduction in task performance degradation. Overall, unit-level degradation could not be assessed for very long periods of operating in MOPP IV (>4 hr). The DO49 studies were the precursor to the U.S. Army P^2NBC^2 studies, which considered small unit-level degradation effects.

The AURA model grew and extended its parent, RCC, and now allows an analyst to study many types of military unit degradation such as heat stress, task-performance time changes, fatigue, and chemical casualties. The Army continues to use AURA for the study of NBC environments. The AURA model is also the basis for the Navy Unit Resiliency Analysis Model used by the U.S. Navy for NBC analysis today.

CWTSAR

In 1981, the U.S. Air Force began a modeling effort to study the effects of chemical attacks on airbases, considered an important component of the conflict assessment because airbases would be seriously degraded by persistent chemical agents. Using a model designed for logistics requirements called Theater Simulation of Airbase Resources (TSAR), which was configured for a Chemical Warfare TSAR (CWTSAR), the Air Force predicted the effect a chemical attack might have on ground crews, support operations, and command and control personnel and processes.

CWTSAR (Middleton, Chevalier, Evans, Felt, & Hayes, 1986) consists of a U.S. Air Force discrete Monte Carlo simulation model of airbase sortie generation (aircraft launches) and operations in a chemical warfare environment. Each simulation consists of multiple trials, with each trial spanning several days of airbase operations and representing a complete friendly Blue and enemy Red scenario. CWTSAR also incorporates the Non-Uniform Simple Surface Evaporation (NUSSE) model (Leggett, 1979) developed by the U.S. Army for chemical agent modeling studies. NUSSE represents the atmospheric transport and diffusion of chemical agents from bombs and tactical ballistic missiles that use bulk release and from munitions that use explosive dissemination. This program provides estimation of liquid deposition, vapor concentration, and dosage patterns for selected munitions, and the NUSSE model is also used with the U.S. Army AURA model.

The TSARINA module within CWTSAR calculates the effects of conventional munitions attack using an assessment of airbase damage model. The model also represents an airbase as a complex target array of which each component (personnel, aircraft, equipment, munitions, spare parts, building materials, and aircraft fuel) is described by size, orientation, location, and hardness. The hardness of the target is defined as the vulnerability of the resources (personnel and equipment) within the target's range.

Sortie generation is represented in CWTSAR by seven types of requirements: (a) on equipment tasks (unscheduled maintenance performed on the aircraft), (b) on aircraft turnaround tasks (servicing, fueling, munitions loading, and reconfiguration), (c) for off-equipment tasks (repair of aircraft parts or components performed in shops), (d) on repair of damaged aircraft, (e) for repair of aerospace ground equipment and support equipment, (f) on munitions assembly, and (g) on civil engineering tasks (repair of runways, taxiways, and facilities).

The capability of airbase personnel to perform sortie-related tasks is limited by availability of resources, aircraft and equipment failure rates, combat damage or loss, and work disruption due to chemical or conventional attacks. Operations in a chemical warfare environment are further hindered by the CPC-imposed encumbrance, causing degradation in both the speed and efficiency of task performance. The Task Time Degradation (TTD) multiplier methodology (Ramirez, Shew, Felt, & Rayle, 1986), developed in support of CWTSAR, provides changes in tasking due to the following: decreased dexterity and tactile sensitivity caused by the protective gloves, vision restrictions, communication degradation in speech and hearing, decreased dexterity caused by the mask and hood, cognitive difficulties, and decreased agility due to encumbrance. Each time CWTSAR simulates the performance of a task, the CWTSAR task distribution is sampled, and the result is assigned the time required for task performance. The performance degradation due to MOPP IV is estimated by associating a TTD multiplier with each task when personnel are wearing CPC. The product of the TTD multiplier added to the required task performance time is defined as the *degraded task performance time* (i.e., the new time to perform tasks when wearing all of the MOPP gear). The task distribution network provides the probability that a task will be performed, the mean time required to perform the task, and its TTD multiplier. Increased times to perform tasks propagate through task networks, contributing to the ultimate total degradation of base sortie capability. Any delay in completing a task will force delay in linked sequential tasks but not in unrelated parallel tasks. Resource availability affects additional task initiation and completion times and causes additional system degradation. Delays in task performance may indirectly affect sortie generation by affecting resource availability.

CWTSAR consists of several thousand tasks to represent sortie generation for F-16 fighter aircraft. The task database, derived from the Logistics Composite Model and containing Battle Dress Uniform time distributions of the tasks, was developed by the Air Force to track maintenance, repairs, and spare part requirements for aircraft. Empirical data on CPC degradation effects were limited; consequently, it was necessary to develop techniques for estimating the data required and to collect quickly large quantities of empirical data from airbase personnel. Data were sparse for on-equipment, off-equipment, and aerospace ground equipment repair tasks. On-equipment maintenance task data were derived (a) using a human abilities taxonomy as an estimating technique and (b) assuming the same TTD multiplier could be applied to similar tasks within an aircraft subsystem that required the same human task performance abilities. Grouping these tasks at the subsystem level reduced the number of TTD multipliers from 1,000 to approximately 400.

RESULTS

Human Abilities Taxonomy Development

The Human Abilities Taxonomy for CWTSAR (Ramirez et al., 1986) was adapted from a taxonomy developed by Fleishman (1982; Fleishman & Hogan, 1978). It applies task analysis procedures of criticality and difficulty for task performance to determine the task time increase for aircraft maintenance and munitions inputs for the CWTSAR model.

Collecting subjective information about military tasks during training exercises lasting 5 days or less yielded data that were validated by collecting quantitative (empirical) timed data for 60 of the tasks represented with the Human Abilities Taxonomy. This approach provided a practical tool for measuring task performance in a stressful environment.

Two factors, criticality and difficulty, were used to conceptually organize the data. The Criticality factor is defined as the level of importance of a human ability to the performance of a task, such as task completion. Personnel subjectively rated the importance, or criticality, of each factor to the task being measured. A 5-point

Likert scale, ranging from 1 *(not important)* to 5 *(most important to task completion),* was used for data collection. The Difficulty factor is defined as the amount of constraint, or burden, placed on the individual by a change in the environment, such as wearing protective clothing. The Difficulty factor is a function not only of the task but also of the particular source of task degradation (CPC encumbrance or heat buildup). The procedure for determining the Difficulty factor was a subjective rating obtained by the personnel performing the task. The 5-point scale for the difficulty ranged from 1 *(no difficulty in ability to perform the task)* to 5 *(extreme difficulty).*

The questions that addressed specific abilities were asked for criticality and for difficulty, using two questionnaires identical in their construction except for the terms *important* (another term used for *critical*) and *difficult.* For example, a question for the physical capabilities was "How important to the task is climbing?" and the difficulty was "How difficult is it to climb when wearing CPC?"

Eight ability categories were identified (Ramirez, Charlton, & Hoffman, 1991) by the human performance analysts as representative of the components required for this military task performance taxonomy. Within these eight ability categories, subabilities for each category were established and are shown in Table 1.

At the subability level, the data could pinpoint areas of task performance problems to assist in resolving the cause of the degradation. The subabilities of each ability were aggregated to provide averages for each ability. The data were then totaled, divided by the criticality sum (weighting factor) for a performance number, and linearly rescaled to fit into the task time multiplier scaling used by CWTSAR. When predictions from this taxonomy were compared to empirical data, the new time to complete tasks was similar for calculated data and empirical data. (A civil engineering task empirical measure found an increase of 1.70 times longer to perform the task; the taxonomic method provided a calculated increased time of 1.76.) For example, the task of engine repair during vehicle maintenance is shown in Table 2.

The product sum for the Criticality factor and the Difficulty factor is 110; the Criticality factor sum is 26. By dividing the product sum by the Criticality factor sum, the average reached is 4.23. This number fit into the range of the 5-point scale and rescaled to the empirical multiplying factors used by the CWTSAR model.

A review of the performance degradation literature and empirical observations revealed that any task taking more than three times longer to complete when wearing protective clothing would be modified by the soldier (task workaround) or not accomplished at all. Therefore, by establishing a conversion scale and using the 5-point scale with no more than three times the original time to perform the tasks, the Likert scale data were easily transformed to a multiplier the CWTSAR model used with the original task times. When wearing CPC, not all tasks require increased time to perform, but when they do, this method provides a quick and relatively simple tool to integrate the changes into the model.

TABLE 1
Listing of Abilities and Subabilities

Ability	*Subability*
Vision	Acuity
	Accommodation
	Distance judgment
	Visual perception
	Color discrimination
	Peripheral vision
Psychological effects	Stress
	Tension (muscular)
	Depression
	Anxiety
	Confusion
	Motivation
Dexterity	Fine motor manipulation
	Fine motor response
	Fine motor strength
Physiological condition	Fatigue
	Stamina
	Adaptation
Cognitive effects	Short-term memory
	Long-term memory
	Retention
	Retrieval
	Storage
	Concentration
	Attention
	Reasoning
Auditory detection	Localization
	Sensitivity
	Speech interference
	Intensity of speech signal
Physical coordination	Motor response
	General mobility
	Strength
Verbal communication	Speech understanding
	Response process

TABLE 2
Human Ability Factors Method

Ability	*Criticality Factor*	*Difficulty Factor*
Auditory detection	4.0	4.0
Cognitive effects	3.0	3.0
Verbal communication	2.0	4.0
Dexterity	4.0	5.0
Physical coordination	2.0	3.0
Physiological condition	5.0	5.0
Psychological effects	2.0	3.0
Vision	4.0	5.0

DISCUSSION

P^2NBC^2 Database

The development of the P^2NBC^2 database began with the Army as part of the AURA modeling efforts. Initially, it used the DO49 field study data, which demonstrated the increased time to perform tasks while wearing CPC. Simultaneously, the Air Force was developing the Task Time Multiplier database for the CWTSAR model. In 1986, personnel from the two organizations developing these databases met to share information because both databases were developed using dBase III and contained similar data fields. In 1987, the best of both databases were merged; the Army database contained 12 fields and the Air Force, 22 fields. The major differences between the two databases were as follows: The Army database contained a training coefficient to account for the effects of learning on performance during the first experiences of an exercise when CPC was worn, whereas the Air Force database contained the human abilities taxonomy developed for task data collection. The training coefficient was discarded in 1987 when the two database systems were merged, and the human ability taxonomy was expanded.

In 1987, the P^2NBC^2 Program Office of the U.S. Army Chemical School assumed responsibility to enter all data gathered from P^2NBC^2 field and lab studies. Today, the P^2NBC^2 database contains over 5,000 records with over 160 fields organized in a relational format. Eight database tables include task data, trial data, mission-related data, MOPP data, operational limits data, demographic data, individual data, and source data (Ramirez & Charlton, 1993). This last database is linked to the seven other databases and provides the report citation for the data and the experimental design for the study.

Although the U.S. Air Force data are still available, the database no longer contains U.S. Air Force ground crew data. Information for Rapid Runway Repair tasks performed by the U.S. Army Corps of Engineers for the Air Force is still available. (The database is available in a Microsoft Access executable for Windows and can be ordered from the Chemical and Biological Information Analysis Center in Edgewood, Maryland.)

The P^2NBC^2 database system has been helpful to test directors performing field and lab studies and for operations research analysts requiring data for modeling efforts. The P^2NBC^2 data collection tool (a format used to extract data in a standard method from each completed field study) is also used in the planning process of each P^2NBC^2 test. This procedure ensures that all data required from a test are collected in an organized, standard format. The data collection tool assists the tester in compiling the data using predetermined methods. U.S. Army Training Evaluation Program, Mission Training Plan (collective soldier tasks) with Soldier Training Plan (individual soldier task) numbers are associated with each task and subtask of a test; MOPP levels, temperature, and humidity readings are also required. Each layer of clothing worn, cooling system used if any, and heart rate of each individual for each trial are collected if available. All these variables are structured and collected the same way for every test performed under the direction of the P^2NBC^2 program office.

The database provides the analyst with information from past studies that can be used for predictive performance modeling as well as comparison and compatibility studies of emerging systems or new operational methods. All P^2NBC^2-supported U.S. Army field studies, DO49 studies, and other studies of CPC performed from 1980 to 1994 were reviewed and validated, and the data were entered into the database. Test directors were contacted to acquire missing information, and the validity of the data was assured before the information was entered into the database. Overall, the data in the P^2NBC^2 database are the most accurate available for modeling human performance in a chemical environment.

The P^2NBC^2 database provides data on the problems with soldier performance while wearing CPC and the increased time to perform tasks when wearing MOPP IV in various weather conditions. The database is available to the U.S. military C–B defense community and was placed in the database inventory at the Department of Defense Chemical/Biological Information Analysis Center; updates are provided each year of the P^2NBC^2 program and lab testing. The P^2NBC^2 database will continue to serve future efforts for designers of new protective clothing systems such as the U.S. Army Training & Doctrine Command Battle Labs concept development initiatives, Distributed Interactive Simulation (DIS), and MANPRINT Soldier Survivability programs.

In the future, military psychologists undoubtedly will be called on again to provide critical human performance data for modeling and simulation environments. As DIS continues to grow, virtual environments and virtual reality will provide new training platforms for the soldier of tomorrow, and attention to psychological issues will be required for combat models with increased emphasis on the soldier as an integrated part of any weapon system.

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Psychological Aspects of Chemical Defense and Warfare

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Concerns about chemical, biological, or radiation (CBR) weapons and their potential for warfare can be very stressful. Such concerns subject people to unfamiliar threats in highly ambiguous situations, in which people feel they may be wronged or they are helpless. Maladaptive psychological overreactions or underreactions may result. Such reactions to chemical warfare are illustrated with experiences from World War I, the 1991 Persian Gulf War, and a 1995 terrorist attack in the Tokyo subway. General principles of psychology suggest strategies and tactics for training and matériel developments that should enhance military performance and reduce maladaptive stress in CBR threat situations. Some of these practices may be relevant to nonmilitary law enforcement and relief agencies that manage CBR threats.

Chemical weapons have been in the inventories of the major powers since World War I. They are also now seen as inexpensive weapons of mass destruction of the Third World countries. The development of biological weapons has made alarming strides recently, which could also make them readily available (Dando, 1997; Gourley, 1997; Hewish, 1997). Despite their availability, lethal chemical or biological weapons have only been used in a few internal, colonial, or regional wars in relatively remote places since World War I. This limitation may result because

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of the universal repugnance these weapons evoke. This repugnance is remarkable because flame weapons seem at least equally horrible; yet, they have been used freely against troops in combat and against civilians in almost every war. The limited use of chemical weapons may therefore be due less to repugnance than to their making any war more difficult and unpleasant. This burden of the defense may be the more important deterrent against first use. If the enemy has the capability of retaliating with chemical agents, or even if forces have to fight in regions contaminated by their own chemical weapons, the operational difficulties of fighting in chemical protective clothing (CPC) will likely grant victory to the force which can best fight in CPC. The key to successful operations in a chemical defensive posture is controlling both physiological and psychological stresses on soldiers.

Reports in the scientific literature (e.g., Driskell, Guy, Saunders, & Wheeler, 1992) and other articles in this special issue describe the encumbrance, heat retention problems, and performance impairments that result from wearing CPC. Although these effects can dramatically limit combat effectiveness, this article focuses on adverse psychological reactions created by circumstances that require troops to wear CPC. The impact and management of psychological stressors associated with warfare with chemical agents will be explored in this article. Insights from combat experience and experimental psychology suggest ways to address the chemical, biological, or radiation (CBR) threat so that the resulting responses to stress are adaptive, and so that we can maintain a truly credible (and hence deterrent) chemical or biological defensive posture.

STRESS-PRODUCING FEATURES OF THE CBR THREAT

Several features of chemical warfare agents are likely to provoke strong emotional and psychophysiological stress responses in personnel who perceive themselves to be at risk of chemical attack (Department of the Army, 1994; Newhouse, 1987; O'Brien & Payne, 1993; B. J. Taylor, 1993). Similar features are found in biological agents and nuclear threats, especially exposure to radioactive fallout.

First, to most people, the CBR threat is unfamiliar, outside normal daily experience. Second, the CBR threat is insidious, both in space and time. Many chemical, biological, and radioactive agents are invisible, silent, odorless, and often undetectable by the human senses until it is too late to protect against them. They also have a shifting, creeping dispersion because of weather and diffusion. When chemical agents are used as area weapons, some CBR agents persist in the area and remain a threat for hours, days, months, or even years. Some can be transported inadvertently from where they were employed and cause casualties elsewhere, including medical care facilities after being transported there by contaminated patients. Although the long-term prognosis of conventional injuries is usually clear, there are scientific uncertainties and great public concerns about the potential long-term consequences of exposure to chemicals, radiation, and some biological agents (Adler, 1994; Beal, 1997; Department of the Army, 1994; Fumento, 1995).

False alarms add to the stressfulness of CBR threats and can cause heightened states of alertness and fear (Boyer & Lako, 1995; Department of the Army, 1994). Such false alarms can result from the varied weapon systems used to deliver these CBR agents (e.g., artillery, aircraft, guided and ballistic missiles, and mines). In the Persian Gulf War in 1991, most detections of Scud missiles launched by the Iraqis triggered chemical alerts throughout much of Saudi Arabia and Israel. However, the U.S. Department of Defense maintains that no Iraqi missiles were armed with chemical or biological warheads (Presidential Advisory Committee, 1996).

Chemical and electronic detectors of chemical warfare agents can also create false alarms. Other false alarms arise because people mistake common bodily symptoms due to minor infectious diseases, allergic reactions, stress, and anxiety for the early symptoms of CBR exposure (Newhouse, 1987). The first signs of many chemical warfare agents include such common, nonspecific symptoms as a runny nose, eye irritation, blurring or dimming of vision, shortness of breath and respiratory distress, tachycardia, diarrhea, skin rashes, and blisters.

Additional stress is created because CBR weapons harm and kill in ways that are widely considered to be unfair and ignoble, even by professional troops (Haber, 1986). The CBR weapons are likely to harm or kill civilians who lack protective equipment or training because these weapons are pervasive and persistent. The perceived "wrongfulness" of such weapons stems from their being seen as "public health and modern medicine in reverse," in that scientific breakthroughs and knowledge of human physiology, disease, and genetics have been deliberately perverted and used as weapons to kill (Harris & Paxman, 1982, pp. xi–xii). There is also concern these weapons might cause destruction on a global scale. Such concern was the subject of best-selling fiction and movies such as *Outbreak* (Kopelson, Petersen, Katz, & Petersen, 1995) and *12 Monkeys* (Roven & Garris, 1995). Subsequently, if troops (and others who have seen such films) believe potent biological agents have been released, they might remember images that could evoke an unprecedented sense of hopelessness.

Another important psychological aspect is that many CBR agents contaminate the air we breathe to stay alive (Department of the Army, 1994). Thus, CBR agents are linked to the most basic and urgent of all biological drives—the need to breathe. If troops do not have CPC, then thoughts about CBR agents could make everything seem out of their control. Likewise, lack of confidence in their equipment or their ability to use it may also evoke a profound sense of helplessness or hopelessness.

PSYCHOLOGICAL RESPONSES TO THE CBR THREAT

Some of the oldest and best documented psychological principles seem pertinent to people's reactions to the threats posed by CBR weapons. One psychological principle is that people usually *overestimate* the risks associated with unfamiliar, ambiguous, and seemingly uncontrollable threats (Nisbett & Ross, 1980). Hence, the risk of exposure to chemical agents may be overestimated because most troops lack familiarity with them. Without knowledge and experience of them, it is difficult to understand and keep in perspective the partial protection offered by clothing or shelter and the protective factors of dilution, dispersion, and weathering when dealing with chemical agents. In contrast, studies show that people *underestimate* the risks associated with familiar, obvious, and readily controllable threats (Nisbett & Ross, 1980). People seem more concerned about the low risks of injury from pollutants or falling satellites than about the greater risks from smoking cigarettes, driving automobiles, or riding motorcycles. In combat, the dangers of artillery, snipers, and other conventional weapons become familiar and seem more controllable by routine actions; therefore, they may be underestimated. Familiar phenomena do not have the same compelling power on most people's imaginations as the threat of CBR warfare agents.

Pavlov (1906) described a second psychological principle. People or animals making discriminations or decisions under conditions of high ambiguity may exhibit high-stress and maladaptive responses. When Pavlov's dogs could not distinguish symbols that were not quite round from the circles that were the stimuli for a classically conditioned salivary response, the dogs exhibited marked physiological and behavioral distress. This syndrome was also observed by other scientists. For example, when the correct choice in a previously learned operant discrimination task became unpredictable, rats developed marked behavioral inhibition, physiologic distress symptoms, and a tendency to respond in fixed ways (Miller, 1965; Miller & Dollard, 1941). These stereotyped responses were so invariant and maladaptive that some rats could not give appropriate responses even when the original conditions were restored (i.e., for a task that should have been easy to solve). Military personnel who must make discriminations in highly ambiguous situations also experience distress. Troops who must fight a guerrilla enemy that deliberately blurs the distinction between combatants and innocent noncombatants are at risk for substance abuse; undisciplined, abusive behavior; atrocities; and posttraumatic stress disorder (PTSD; DeFazio, 1978; Williams, 1980). Such observations suggest that strong aversive emotions, ambiguous information, and situations that require difficult choices can be debilitating.

A third principle is that situations involving perceived wrongfulness make coping more difficult than those that seem fair. Troops cope poorly if they sense they are the object of deliberate malice, injustice, or negligence. Such wrongs produce more distress than do perceived acts of God or legitimate acts of war. The sense of wrongfulness forms cognitive barbs that fasten experiences of fear, helplessness, or disability into the mind and make them unforgettable and unacceptable. This stress can energize victims to seek redress, compensation, or revenge, which may or may not be appropriate for the circumstances. The Buffalo Creek incident and other disasters suggest perceived wrongfulness is a contributor to PTSD (DeFazio, 1978; Weisaeth, 1993; Williams, 1980).

A fourth principle is that a sense of profound helplessness can have strong psychological and physiological effects. Wild rats were captured and tested in the lab (Richter, 1957). Many rats died quickly when immersed in cold water; attached electrodes recorded their hearts slowing and then stopping. In contrast, similar rats who were rescued seconds before impending death, swam for some time when immersed again; they learned to have "hope" in this situation. Other laboratory animals subjected to unavoidable shock in their home cages developed learned helplessness (Seligman & Maier, 1967) from a single experience with shock. The experience produced an avoidance of stimuli like the original aversive situation and a long-conditioned arousal. With repeated unavoidable shocks, most animals eventually became passive, appearing clinically depressed and showing behavioral and physical signs of debilitating stress. This paradigm of Seligman and Maier is one of the models for the etiology of PTSD.

Thus, extreme unfamiliarity, high ambiguity, a sense of being wronged, and perceived helplessness and hopelessness to the CBR threat can interact synergistically to produce maladaptive responses in combatants. These responses are especially dysfunctional because they interfere with finding and pursuing adaptive strategies for coping with the threat.

BEHAVIORAL MANIFESTATIONS TO THE CBR THREAT

Some anxiety about the dangers of a CBR attack is adaptive and prompts individuals and organizations to take appropriate protective measures. However, excessive anxiety, caused by overestimation of dangers of chemical agents, can produce a variety of maladaptive overreactions (Department of the Army, 1994; O'Brien & Payne, 1993). Likewise, when troops do not know how to respond, they may use underreactions to avoid feeling anxious, but insufficient concern can also be maladaptive. These classic psychological defenses and reactions observed in combat and crisis situations are shown in Table 1.

Maladaptive overreactions involve excessive anxiety and arousal. Although moderate levels of anxiety (arousal or motivation) can enhance task performance, excessive arousal interferes with performance, according to the Yerkes–Dodson law (Lindsley, 1966). Skills (tasks) practiced under conditions of high arousal can become automatic and more resistant to performance disruption in stressful situations because of context-dependent learning (Baddeley, 1982).

Phobic avoidance, for example, "gas mask phobia," can develop to objects or situations that are too anxiety provoking (Ritchie, 1992). When unable to escape or avoid the phobic situation, troops may become agitated, irrational, depersonalized, and may even panic (O'Brien & Payne, 1993). For example, they may tear

TABLE 1
Maladaptive Reactions to the Chemical, Biological, or Radiation Threat

Overreactions	*Underreactions*
Anxiety (impaired performance)	Denial (shifting attention to less frightening topics)
Phobic avoidance, panic	Fatalism (thinking all defense is futile, so why try?)
Obsessive compulsive decontamination	Rationalization (finding reasons not to train in chemical protective clothing)
Congregation in safe areas, excluding others	Intellectualization (all knowledge, no practicing of skills)
Hoarding or stealing chemical protective equipment	Overconfidence (in reassurances, equipment, and training)
Hypochondriasis, excessive sick call (may be epidemic)	
Worry-induced symptoms (psychophysiological and conversion types)	
Inappropriate self-administration of antidote (atropine)	

off the gas mask or run wildly without regard for anything. Panic can also be epidemic. Stampede can occur when highly stressed troops suddenly see someone running and believe their only chance for survival is immediate flight and that their escape route is closing or blocked. Conversely, when some people are faced with a seemingly unanswerable threat, they become immobile, freezing in place.

Groups or individuals who fear CBR threats are likely to congregate in safe areas or inside collective protection because of anxiety and may find excuses to stay inside. Those inside may even refuse to let others in for fear they bring contamination, as occurred during the Gulf War when medical personnel in a bunker for collective protection refused to open the door for one of their physicians. He arrived late and without his mask. Those inside kept him pleading outside for over half an hour until the official call came for "all clear"; they disregarded the military police who arrived and assured them that there had been no missile attack. Troops may also hoard or even steal protective items. They may develop obsessive concern with decontamination procedures, which they then perform compulsively. Not only can this consume time needed for other tasks and waste scarce decontamination supplies, but excessive skin cleansing with decontamination solutions can cause rashes that might then be misinterpreted as confirmation of exposure to a chemical agent.

Another common group of overreactions involves development of bodily complaints, that is, somatization, which result in dramatic increases in reports for sick call or visits to the doctor (The Adjutant General, 1979; Weisaeth, 1993). This hypochondriasis occurs as people focus attention on their bodies and internal sensations, looking for the warning signs of chemical exposure they have heard or read about. People can even worry themselves into feeling real symptoms and exhibiting real signs. Others symptoms occur as the consequence of anxiety amplifies normal physiological responses, such as hyperventilation when anxious, which can then become epidemic. If a soldier hyperventilates and mistakes the muscle spasms and tingling of fingers and toes as signs of chemical poisoning, others who observe the symptomatic soldier may become anxious, hyperventilate, and develop the same symptoms. Other symptoms with great psychological impact and with epidemic potential are nausea and vomiting, dizziness, pseudoepileptic seizures, weakness, and fatigue.

Troops who mistakenly believe they have been exposed to a nerve agent may self-administer an antidote (atropine). It is possible that 4 mg of atropine could potentially induce an anticholinergic delirium and overt psychosis in a seriously sleep-deprived, dehydrated, and anxious soldier (Caldwell et al., 1991; Weiner, 1980).

The underreactions that arise from psychological defenses to avoid anxiety (see Table 1) can also be maladaptive and inhibit preparation and countermeasures, which can be deadly if chemical agents are actually employed (Department of the Army, 1994). They interfere with training and with selection of optimal protection for an actual threat situation. Troops may be lulled by their psychological defenses and may leave their protective equipment behind or even discard it as unnecessary.

HISTORICAL REACTIONS TO CHEMICAL THREATS

World War I

In combat involving chemical warfare agents during World War I, psychological stressors caused more casualties than did chemical injuries. Stress cases were labeled gas hysteria, gas mania, or gas neurosis. The official U.S. Army Medical Department history (Medical Department of the U.S. Army in the World War, War Department, 1926) cites two such psychological (stress) casualties for each actual chemical injury. As an example, only 90 out of 281 gas casualties at one field hospital in the division rear showed signs of any chemical injury. It is believed that the cases without chemical injuries included: (a) experiencing conversion-type disorder with psychogenic signs and symptoms, (b) mistaking normal physiological stress symptoms for exposure to gas, (c) mistaking and magnifying symptoms of minor illnesses, and (d) deliberate faking or malingering. In addition, some troops with actual injuries from chemicals involved disproportionate pain or disability for their minor injuries. Some cases even had chemical injuries, suspected of being deliberately self-inflicted to escape battle (B. J. Taylor, 1993).

The U.S. Army Medical Department found that evacuation of sufferers of gas hysteria to a safe and comfortable rear-area hospital tended to make the symptoms intractable and chronic (Medical Department of the U.S. Army in the World War, War Department, 1927), a finding similar to that for war neurosis (popularly called *shell shock*). Recovery was best if reassurance and explicit expectation of rapid return to duty was given to the patient at medical aid stations and triage points near the battlefront, where, with simple reassurance, troops could be returned to duty within minutes or hours. If troops were evacuated to the rear area, however, it generally took several days for them to recover from their psychological symptoms, with some troops developing persistent gas neuroses.

Troops with gas neuroses were evacuated to facilities located relatively close to the front, where, in specialized psychiatric treatment facilities, the U.S. Army also treated the persistent cases of war neuroses. These facilities maintained a highly structured program of therapeutic activities and ward morale that focused on the soldier's rapid return to duty.

Statistics of medical casualties underestimate the total number of dysfunctional stress cases because they do not include troops who bolted in panic at the threat of gas attack, unless those troops were subsequently evacuated for medical care. Panic reactions were triggered by many events (Medical Department of the U.S. Army in the World War, War Department, 1926; Newhouse, 1987); when rumors suggested new chemical agents could penetrate the gas masks, whole units fled after smelling an unfamiliar odor. Units who were exhausted or demoralized were especially susceptible to panic.

Lessons during World War I suggested that combat experience with the chemical threat often led to positive psychological adaptation. Training was developed to build confidence in the gas mask and motivate troops to use it. Gas chamber training using tear gas had troops wearing their gas masks for more than 1 hr in the chamber before they took them off to experience the effects of a simulated chemical agent (Haber, 1986). Most veterans preferred the odds offered by chemicals to those of conventional artillery—about which troops could do nothing if the projectile fell on them. Marshall (1979) emphasized this view by saying: "We had a main chance to beat poison gas if we acted sensibly, but common sense could not neutralize a bullet or a shell shard" (p. 15).

Newly assigned troops sometimes died in gas attacks if they lacked adequate training and mentors, just as they were more likely to be victims of conventional weapons. It was also recognized that chemical weapons wounded far more than they killed (~30:1) compared to conventional weapons (~3:1). Many victims of chemical attacks recovered and returned to duty, although many others suffered permanent injury and disability. The survivors of chemical attacks were troops who had mastered the drill and tactics of chemical defense.

World War II

U.S. forces tried to maintain a high state of readiness, requiring troops to carry gas masks, gas capes, and protective covers. Before the North African and Normandy invasions, the army impregnated field uniforms with an oily substance to make them resistant to the chemical agent mustard. As the primary chemical weapon of the United States, mustard was kept close behind the front, in both the European and Pacific theaters, for rapid use in retaliation, if needed, but chemical agents were never used in combat by any country in World War II.

Post Vietnam War

The use of chemical and perhaps biological weapons by the Soviet Union or client states in the Yemen Civil War, Laos, Cambodia, and Afghanistan is difficult to verify. This illustrates the ambiguity inherent in documenting use of CBR warfare in remote areas. Mustard and nerve agents were used by Iraq in the 1979–1980 Iran–Iraq War and against Kurdish villages in Iraq (Stuteville, 1997).

Desert Shield and Desert Storm

Since World War I, the U.S. military forces have experienced no chemical warfare. In 1990–1991, however, U.S. Army troops gained some practical experience with protection against chemical warfare in the Persian Gulf region during Operations Desert Shield and Desert Storm (Adler, 1994). Desert Shield involved a 5-month military buildup under a constant state of alertness and training for chemical warfare, and the 100-hr ground offensive occurred in February and March of 1991 during the wet, windy desert winter, when heat stress in CPC was unlikely. Operation Desert Storm brought Iraqi Scud missiles striking deep into the rear (Saudi Arabia) but presumably only with explosive, nonchemical warheads. Mission-Oriented Protective Posture (MOPP) was practiced by most units; however, some troops presumed each alert was another false alarm and did not take reasonable precautions to protect themselves from the possibility of attack with chemical warfare agents (Gulf war veterans, personal communications, 1991–1997). Troops who went out unprotected to watch "the fireworks" as the Patriot missiles intercepted incoming warheads were apparently unaware that even a successful interception could still rain down liquid or thickened nerve agent.

The Israeli civilian population was subjected to many Iraqi Scud missile attacks and had to rely on gas masks plus improvised, expedient, collective protection (Golan, Arad, Atsmon, Shemer, & Nehama, 1992; Müller, Yahav, & Katz, 1993). Many stress casualties were seen at Israeli hospitals, several of whom believed they had been gassed (Eshet, Margalit, Shalom, & Almagor, 1993; Golan et al., 1992; Müller et al., 1993).

No deliberate use of chemical weapons is documented during the Persian Gulf War (Adler, 1994; Presidential Advisory Committee, 1996); however, there is a documented case of minor mustard burns on a soldier who entered an Iraqi bunker (Presidential Advisory Committee, 1996). There were no documented clinical cases of nerve agent poisoning among the U.S. or Coalition forces or among the captured

Iraqi prisoners. It may be that highly publicized U.S. preparedness and capability to fight in MOPP produced the effective deterrence. Although the alarms of chemical detectors were triggered repeatedly, most were thought to be false alarms. Air attacks on Iraqi factories and depots during the air campaign and demolition of bunkers at Khamisiyah, Iraq, after the cease-fire probably released chemical agents into the ascending fireballs and smoke (Presidential Advisory Committee, 1996). Belatedly, the Central Intelligence Agency offered a formal apology to Gulf War veterans in April 1997, acknowledging that they knew about the chemical agents and munitions in the bunkers at Khamisiyah from intelligence data gathered years earlier (New York Times News Service, 1997).

There are eyewitness and clinical accounts of many maladaptive reactions (O'Brien & Payne, 1993; Gulf War veterans, personal communications, 1991–1997). Examples include a sergeant with gas mask phobia who was evacuated all the way to the United States, other cases of gas mask phobia that were treated successfully with behavioral therapy in the theater, at least one case of atropine self-injection, and the incident involving the physician mentioned previously, who was barred from entering a protective shelter by fellow soldiers after an alert because they feared he would contaminate the shelter.

Gulf War Veterans' Illnesses

Some veterans of the 1991 Gulf War in Kuwait and Iraq now suffer from complaints such as insomnia, disabling fatigue, malaise, hair loss, bleeding gums, joint and muscle pains, skin sores and rashes, gastrointestinal and respiratory difficulties, and memory impairment. Initially, these disorders were called *Persian Gulf Syndrome,* a label that persists in the media despite official attempts to replace it with *Persian Gulf War Veterans' Illnesses.* The preferred label emphasizes that there is more than one syndrome and that there are many different causes. In fact, some of the casual factors occurred most likely before the Gulf War itself (Presidential Advisory Committee, 1996).

Since Operation Desert Storm, rumors and allegations of the enemy's use of chemical and biological weapons have abounded among Gulf War veterans, their families, and the media (Adler, 1994; Boyer & Lako, 1995; Ficarra, 1995; Flanders, 1995; Fumento, 1995; Griswold, 1995; Nelson, 1994). Veterans speak of their anxiety and frustration that their government has not recognized and documented that their nonspecific, debilitating symptoms are due to toxic exposure in the Persian Gulf campaign. Specifically, they suspect subclinical doses of Iraqi mustard or nerve agent, unknown infectious biological weapons, or thallium (a rare element) were delivered covertly in the warheads of Scud missiles (Adler, 1994). Some also blame medication (pyridostigmine bromide) or vaccinations (to protect from anthrax, botulin toxin, etc.), which U.S. troops received involuntarily to protect against Iraq's chemical and biological arsenal (Presidential Advisory

Committee, 1996). Two researchers claim they found a genetically engineered mycoplasm in the serum of some Persian Gulf veterans (Presidential Advisory Committee, 1996), which they believe was developed and tested on prisoners in the United States and then supplied to Iraq. Other exposures and combinations are also proposed (Adler, 1994; Ficarra, 1995; Fumento, 1995).

Whatever the causes of Gulf War Veterans' Illnesses, the high stress from the ambiguity of long-term consequences of the veterans illnesses was evident in sufferers as they testified before U.S. congressional investigating committees. Some veterans of the Gulf War were in tears as they talked of not knowing how long they will live, what they will die of, and whether the illness is afflicting their spouses and children. The extreme ambiguity of the threat (especially 6 to 7 years later) makes it difficult to provide convincing reassurance or long-term prognosis to those affected. These troops and their families express frank anger and feel betrayed by the perceived failure of their leaders to protect them during the war or to take their complaints seriously immediately after it.

The irony is that high stress engendered by unfamiliarity, ambiguity, sense of being wronged, and feelings of helplessness can make for self-fulfilling prophesies of worsening symptoms. Stress involves changes in the physiologic, neuroendocrine, and immune systems of the body—changes that can bring on real illnesses that can result without any chemical, biological, or radioactive "trigger event" (Presidential Advisory Committee, 1996; Selye, 1993). The sufferers and their proponents are angered whenever anyone suggests that it is merely stress that is causing or worsening their symptoms. They might be more assured if they understood that stress is a physiological process that causes real physical (not imaginary) signs and symptoms. Cognitive behavioral training might transform their self-perception of aggrieved and helpless victim to a self-perception of resilient and adaptive survivor (Meichenbaum, 1994).

Terrorist Attack in the Tokyo Subway

The CBR warfare agents have also been used as weapons by terrorists during peacetime. In 1995, members of a Japanese religious cult released chemicals, primarily the nerve agent sarin, into the Tokyo subway (Altman, 1995; Lillibridge, Liddle, Leffingwell, & Sidell, 1995). The psychological effects of this attack on totally unprepared and unprotected civilian commuters confirmed the tendency of many victims to experience symptoms and seek care in the mistaken belief that they were injured. This episode also illustrates how the media can create and perpetuate misleading information and exaggerate the ability of chemical agents to cause serious physical harm.

Newspapers and television in the United States reported that 12 people were killed and 5,500 were "injured" by the sarin attack in the Tokyo subway (Altman, 1995). Findings from 5,110 victims evaluated at hospitals in the first 24 hr documented the overreactions and concern chemical warfare agents create (Lillibridge et al., 1995). Overall, 73.9% of these casualties showed no effects of exposure to nerve agent. These patients were the worried well!

The reactions of a small percentage of the victims were serious; 0.15% (eight people) were dead on arrival, and 0.31% required ventilatory support and individualized care. Another 17.9% were hospitalized showing pinpoint pupils (miosis) and temporarily disturbed vision, which can be caused by exposure of the eyes to a minute amount of nerve agent. Miosis and disturbed vision are minor effects because, in combat, troops presenting only these signs and symptoms would not be hospitalized. Another 0.67% of cases showed these visual disturbances and possible signs of systemic poisoning (weakness and respiratory distress) but did not require ventilatory support. For 7.1%, their clinical status was undocumented.

This terrorist attack involving chemical warfare agents against civilians illustrates several things. First, over 95% of the presenting concerns were minor or nonexistent; the incident produced 1 immediate fatality for every 130 injuries. Second, the ratio of purely psychological to physical casualties is ~3:1 to 4:1. Comparing these findings of the sarin attack in the Tokyo subway to the 2:1 ratio (number of psychological casualties to number of physical casualties) from trained U.S. troops in World War I suggests the value of military training in chemical defense in reducing the number of psychological casualties. Third, these data highlight the importance of identifying and reducing psychological overreactions to a crisis that overburden the medical support system and overload critical personnel during a crisis. Fourth, even 2 years later, this incident is still being reported as a situation where "twelve people were killed and more than 6,000 passengers fell ill in the nerve gas attack on five Tokyo subway lines" (Reuters, 1997, p. A5). This and other similar recent accounts highlight how the media can sensationalize and unknowingly exaggerate the threat of CBR weapons.

TRAINING FOR CHEMICAL DEFENSE EXERCISES AND WARFARE

If the unfamiliarity, ambiguity, wrongfulness, and helplessness engendered by CBR agents contribute to maladaptive psychological reactions, several remedies are implied. Information about the chemical agents and improvements in detection technology can reduce the unfamiliarity and ambiguity, and much more can be done with the protective measures to increase familiarity and to decrease ambiguity about their use. The idea of the wrongfulness of using CBR weapons should be encouraged because it may inhibit their use, except by rogue states or terrorists. However, our leadership must avoid even the suspicion of wrongful behavior, such as false reassurances, negligence, or unethical experimentation.

Most important, there are several strategies that may help reduce the sense of helplessness: by adding greater flexibility to protective doctrine to cover contingencies when anticipatory donning of full CPC may not be feasible, by dividing the seemingly insurmountable CBR threat into manageable pieces that can be taught separately in training, and by improving soldiers' confidence in the gas mask as protection against the threat of breathing CBR agents. Because the vaporous form of the chemical warfare threat is the most common, rapid, deadly, and least reversible form of exposure, the vapor threat deserves a high priority for mastery. In addition, training for protection against the skin-contact hazard should continue.

When leaders describe the anticipated conditions of combat, they should explain that it is unlikely that chemical weapons will be used, but the U.S. Army trains for that possibility because we are smart, survival-conscious, professional troops. Leaders should also point out that a potential enemy may be deterred from a first-time use of chemical weapons if our troops show by their routine training that chemicals will not defeat them. History has shown that deterrence worked in World War II and the 1991 Gulf War, but we must continue our efforts to make it successful. Rather than generate fear of chemical threats, we should capitalize on professionalism and standing operating procedures during training.

Soldiers cannot be completely safe on any battlefield with conventional weapons nor can they be completely safe from CBR agents. Training must give soldiers the familiarity and confidence that they can use the CPC flexibly, integrated with the risk appraisals they make about the enemy and environmental threats. The following recommendations for training utilize general psychological principles to help soldiers achieve their best odds for survival and success on a potential CBR battlefield.

Frequent and Extensive Training With the Gas Mask

In today's world of ballistic missiles and terrorists, most military units are subject to sudden chemical attack. Considering the CPC, the gas mask provides all of the protection against the sudden and unforgiving vapor threat. The gas mask also prevents agents that harm the skin from entering the eyes, lungs, and respiratory tract. Every soldier must be able to do all essential mission and survival tasks after wearing the gas mask for many hours. However, the gas mask is also the source of much of the psychological stress (claustrophobia); respiratory distress; decreased vision, hearing, and clarity of speech; and decreased social and environmental cues (Bensel, 1997/this issue; Johnson & Kobrick, 1997/this issue; Muza, Banderet, & Forte, 1996; H. L. Taylor & Orlansky, 1993). These can be counteracted somewhat by training in breathing and relaxation techniques, positive imaging, positive self-talk, and learning to modify and pace tasks. Routine practice with instructors and good role models are the best way to overcome most of the performance difficulties. Therefore, in training and in combat, it is important to wear the gas mask frequently (like the helmet, which also protects a crucial part of the body), even at low levels of risk.

All the unit's personnel, whether in the field or garrison, should wear the gas mask at least 1 hr each day, whether they are wearing the battle dress or physical training uniform or office clothing. Each soldier should have his or her own properly fitted gas mask to keep and maintain. The mask should be provided with corrective lenses if needed. Soldiers are more likely to develop a grudging "cohesion" with the gas mask if they feel ownership for it and know that comfort and perhaps life itself may depend on the mask.

A psychological complaint is that the gas mask and CPC make everyone look identical and hide the usual cues by which one recognizes team members, leaders, and followers. Consideration should be given to developing ways to put distinctive symbols on the face part of the hood to represent the team, larger unit, rank, and individual soldier. However, symbols placed on the mask must not compromise durability, camouflage, operational security, and public sensibilities. When practiced as a group, activities in the gas mask will build esprit de corps, and the team assistance and organizational and social encouragement will help overcome difficulties encountered. Everyone does not need to be masked at the same time, and the hood does not need to be strapped down over the neck and shoulders in a mask-alone posture. Training should build up progressively until everyone can wear the gas mask for 8 hr or more. Troops should practice sleeping in the mask after receiving advice on ways to maintain the gas mask's protective seal and prevent respiratory distress or intermittent obstruction of breathing (sleep apnea).

Frequent Training With the Gloves

The same principles that apply to adapting to the mask are also appropriate for working with the protective gloves. These can be worn for 1 hr per day on a regular basis, with or without the gas mask or the rest of the CPC while doing a range of tasks. With practice, soldiers will learn to compensate somewhat for the decreased dexterity and tactile sensitivity associated with wearing the gloves (Bensel, 1997/this issue; Johnson & Kobrick, 1997/this issue; King & Frelin, 1984).

Adapting to CPC

To overcome initial anxiety and help troops function and familiarize themselves with CPC, they should start out with enjoyable activities. Games such as cards, dominos, checkers, electronic games, volleyball, and softball can be good ways to introduce and periodically sustain a program of mask alone (and later MOPP) training. Some personnel in Desert Storm played volleyball while wearing the gas mask to gain experience wearing it. Personnel from the southern United States, who routinely wear protective uniforms to process toxic environmental wastes, play volleyball and perform other enjoyable activities in CPC to facilitate adaptation and behavioral compensations (Lawren, 1988). The equipment should promote confidence and mastery faster in familiar, enjoyable situations; however, leaders must insist that the items of CPC are always used correctly, even in nontactical, "enjoyable" situations and make clear that there must never be any "fooling around" with the gas mask or CPC.

Several advantages result from wearing the gas mask and gloves frequently under varied routine, low-stress conditions. Repetitive and frequent trials, distributed in time, greatly facilitate learning. Such training also provides opportunities to observe positive role models dealing with the same practical psychological problems. Each progression of increasing stress is usually tolerable and can be mastered.

This approach also approximates Systematic Desensitization, a therapeutic strategy helpful for overcoming strong phobias and aversive and debilitating emotions (Wolpe, 1958). This procedure introduces more and more of the feared stimuli (e.g., fear of wearing the gas mask and full CPC) while performing routine, nonstressful, and relaxing activities. People who are inadequately trained or psychologically insecure should not be exposed immediately to the full stress of full CPC. Likewise, adaptation to the gas mask is not confounded with the stress from wearing the rest of the CPC.

Managing Heat Stress for Troops Wearing CPC

Training can be hard and long with physically fit and well-acclimatized troops. To be combat ready for operations in CPC, troops must experience some heat stress during training. However, physically unfit, unacclimatized troops should never exercise in extreme heat or in CPC. Leaders should accept the risk of troops training hard in CPC only after a specific and rigorous physical preparation of every soldier in the unit. Physically fit troops can be acclimatized to heat by exercising progressively in hot conditions (or wearing CPC), starting with brief, relatively low ambient temperature exposures. Then, troops should build up slowly over several days to more intense exercise in higher temperatures (Burr, 1991; Sawka et al., 1995). Under ideal conditions, most acclimation to heat can be realized in 7 to 14 days (Sawka et al., 1995). An extensive study of Marine recruits during basic training showed that increased physical fitness of recruits decreased the incidence of exertional heat illness during physical training (Kark, Burr, Wenger, Gastaldo, & Gardner, 1996).

Everyone must be alert and fully prepared to recognize and manage the signs of mild heat stress in themselves and fellow troops (Burr, 1991; Sawka et al., 1995). Mild heat stress includes heat cramps, heat exhaustion, clumsiness, headache, and the appearance of such mental symptoms as elation, irritability, and confusion. It is critical that every soldier and leader recognize these signs and symptoms in themselves and others. When these warning signs occur, the sufferer must be helped and should stop physical activities and take steps to prevent further overheating, preferably by simply resting without coming fully out of CPC. If symptoms worsen to include the early signs of impending heat stroke, the soldier must be taken out of CPC and cooled (Burr, 1991; Sawka et al., 1995).

Water should be available during physical training exercises, and command emphasis used to assure that all troops follow a prescribed drinking regimen of the appropriate replacement volume per hour (Burr, 1991; Sawka et al., 1995). Troops should practice personal hygiene and other preventive medical measures. Alert medical personnel should be ready to aid any soldiers who show early signs of heat stress; to the extent that it can be done safely, mildly heat-stressed troops should return to the training exercise after they have recovered during brief "time outs." However, emergency capabilities for cooling and medical evacuation should be available to anyone who begins to spike an excessive body temperature. When the brain and body become overheated, further disorientation (and perhaps belligerence) and hallucinations develop, and an affected soldier can progress rapidly to extreme fever, coma, seizures, permanent damage to the brain and body, and death (Burr, 1991). Extensive experience with Marine recruits performing exertional activities in the heat shows that, if medical assets are properly trained and experienced, military units can perform physical training with heavy work demands with few exertional heat casualties (Kark et al., 1996).

Building Up to Prolonged Exercises in Full CPC

With training and practice, every team should build up to 8 hr or more in CPC and perform all of the team's tasks and activities, including sleeping, that would be performed in a contaminated environment. An alternative for training in CPC is for everyone to put on extra clothing, such as a second field jacket and pair of trousers to approximate the bulkiness and heat-retaining qualities of CPC.

The challenge for leadership in training for chemical warfare is to achieve familiarity with the CBR threat without breeding contempt. Leaders must prevent overestimation of the threat or actions that result in underestimation, complacency, or negligence in troops. One approach is to use drill and routine, for example, practicing common soldier tasks and all life- and mission-essential team tasks until they can be done with facility in CPC. Then, by cross training in specialty tasks, everyone can rotate duties during sustained operations, which may allow troops to take brief sojourns into collective protection to get rest or maintain personal hygiene. Troops should practice drinking water through the drinking tube of the mask. They should also practice target identification, vigilance, challenge for friend or foe, and coordination procedures extensively in full CPC (i.e., at MOPP IV). This counteracts the alarming tendency for fratricide (accidental harm to friendly forces) when personnel are in CPC (Draper & Lombardi, 1986). Encapsulation in CPC, the resulting sense of isolation, and degraded sensory information foster an uneasiness in troops, sometimes causing them to shoot first without questioning. In CBR defense training, it is especially informative to use the Multiple Integrated Laser Engagement Simulation system (Fobes, Roberts-Gray, & Ritenour, 1986), or some equivalent system, to accurately assess who "shot" whom.

It is also important to train troops for hasty decontamination of exposed skin and essential equipment. Such exercises should use simulants such as methyl salicylate (a nontoxic liquid that acts like some chemical threats) to verify the effectiveness of decontamination and use chemical detectors and simulants to demonstrate how agents of chemical warfare disperse and how they can be avoided. Familiarity with field-expedient cover and improvisations with simple items like disposable plastic sheeting and tape can reduce contamination of the CPC and sustain hope if replacement of CPC is delayed. For situations in which chemical attack is possible, but not imminent, leaders should accustom their troops to having some unit members in full CPC, monitoring detectors but avoiding heat-producing work. Others, wearing lower levels of protection, can perform tasks that cannot be done safely in CPC under the environmental conditions. If sudden attack comes, the exposed members can take cover and don increased protection while the protected members aid them and continue the mission. Leaders should highlight that such teamwork is a common way to face conventional threats and can also reduce ambiguity and risk in CBR scenarios. Such feats of mastery will counteract the sense of troops being helpless victims and will promote an individual and team identity as ingenious and aggressive survivors.

Demonstrating Mastery in the Gas Chamber

As each member of a team wearing his or her own gas mask enters the chamber filled with tear gas, this experience can be billed as a confidence exercise or test of the gas mask. Troops should not be forced to inhale the tear gas as a way to demonstrate the benefits of the mask or as an attention-getting tactic during the gas chamber exercise. The objective of such training in the gas chamber should be to build soldier skills and confidence in their equipment (Fatkin & Hudgens, 1994). Experiencing the aversiveness of the tear gas and the body's response to it may condition anxiety, upper respiratory symptoms, and avoidance behaviors to the mask itself.

IMPLICATIONS AND FUTURE DEVELOPMENTS

Understanding the psychological principles that make the CBR threat peculiarly stressful provides some suggestions for changes in doctrine and training for chemical defense. These suggestions should decrease the unfamiliarity, ambiguity, and sense of hopelessness that are sometimes associated with training for chemical defense or anticipating warfare with chemical agents. The greatest potential gains exist in the domains of the effects of repeated exposure to stressors, time course of exposure to stressors, pace of stressors, and phenomena associated with recovery from stress (Breznitz & Goldberger, 1993).

Optimizing CPC, Mission, and Combat Theaters

Future warfare will be highly mobile and will often be fought in urban and suburban areas. Combat will be dynamic and require initiative and actions by teams or individuals to cope with fast-moving, changing situations and sites of resistance. Currently, the CPC of the U.S. Army protects troops from many CBR threats; however, this special issue emphasizes that CPC also imposes several performance, physical, and psychological liabilities for the battles that will be waged.

Evolving doctrine, training, and advances in matériel should optimize practices associated with wearing CPC and find new ways to reduce the limitations of CPC so that troops can function effectively in future CBR warfare. The current manual for CBR protection for the U.S. Army and U.S. Marines (Department of the Army, 1992) devotes one page for describing a mask-only posture and variations to MOPP. This is a beginning! Ideally, a full-scale effort would involve computer modeling. Some salient variables to investigate are the capabilities of CBR weapons from different countries, these countries' ways of deploying CBR weapons, likely theaters of combat and their climates, type of CBR agents (vapor vs. skin penetrating), protection from varied components of the CPC, and expected missions. Such iterations would synthesize expert information on risks and likelihood of respiratory and skin-contact threats, the protection that components of CPC such as gas mask or lighter-weight overgarment would offer for special situations, and the increased comfort and performance that would be realized from lighter CPC or gas masks with less inspiratory resistance. Such an effort would facilitate reexamination of current procedures and assumptions of MOPP. Such efforts would ensure that the CPC of the future sustains military performance and offers optimal protection against the CBR threat.

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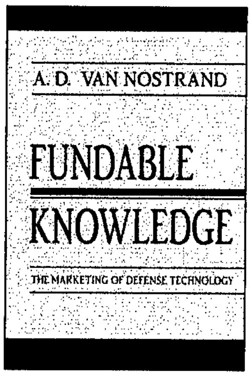

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